NEXT MEETING, NOV. 20th. "The Storage Battery Outlook." See p. 630.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

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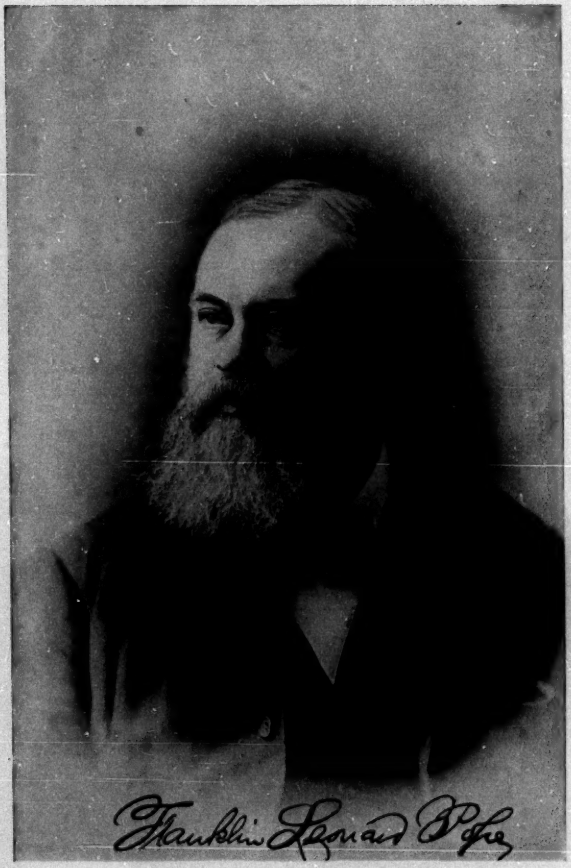
Franklin Leonard Pope

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Twelfth General Meeting.

[Continued from page 493.]

Niagara Falls, N. Y., June 27th.—Morning Session.

President Duncan called the meeting to order and announced that Dr. Emery would speak briefly in continuation of the discussion on his paper of last evening.

Dr. Emery:—In conversation with a number of those present it has appeared that it would be of interest to state a case where electrical transmission was *not* the best means to employ. It was hardly applicable in the discussion of Dr. Crocker's paper, so I will now give a brief outline of the case as a continuation of the discussion of last evening. I was recently called in consultation in regard to a steam plant in the refineries of one of the oil companies in which there were burned, in four boiler houses, about 80,000 tons of coal a year. There was a large number of pumps for transferring the oil, large and small steam engines, and steam and hydraulic pumps in various buildings, so that steam from about 3,000 boiler horse-power was delivered for power, independent of which more than this amount of boiler power was required for heating purposes. The executive officers were experts in their line, and had studied out a large variety of ways for obtaining economy in fuel. They had thought of the plan of taking out the steam pumps, and putting in power pumps operated by economical engines, and exhaust heating was to some extent used, but as a general system, had not received direct attention. Finally in consultation with the electrical people they became interested in a large electric transmission system. It was proposed to put a multiphase generating plant of about 3,000 kilowatts capacity near one of the boiler stations, where high pressure steam could be secured to operate engine dynamos and transmit power electrically through an underground line and multiphase motors in different parts of the buildings and grounds, the lighting being

incidentally done by the same plant; the steam for heating, however, to be supplied by the other boilers. The change would cost a considerable sum of money, and my advice being asked professionally, I saw at once it was not a case where a general system of electric transmission was applicable, but advised raising the back pressure on the uneconomical engines, and distributing exhaust steam to the several heating points, meanwhile providing to put in a small multiphase plant of 75 kilowatts to replace three smaller electric lighting plants, and operate a few multiphase motors at different parts of the yard where the steam pipes were very long and much exposed. The results at last accounts, before the work was fully completed, was that two out of the four boiler houses were shut down, and coal was being saved at the rate of about 40,000 tons per year. This case is simply an illustration of the fact that electricity is not a "cure-all." It has its desirable features, but sometimes there are other ways by which the results desired can be accomplished much more satisfactorily. The question may be asked what the relative saving in fuel would have been to carry out the first plan, using large economical units to generate the electrical energy, but running extra boilers to do the heating. The difficulty with this plan was, that the heating was so large a portion of the work, that by generating steam and running it through the engines first, the exhaust steam would develop the power for practically little more cost than the thermal losses in the transmission of steam. In other words, the engine dynamos, the transmission plant and motors should, in order to compete with steam, furnish the power with a quantity of steam sufficiently less than that *condensed* in the steam transmission plant, to pay the interest on the investment in the electric plant.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th, 1895. President Duncan in the Chair.

THE CAUSE OF DEATH IN ELECTRIC SHOCK.

A. M. BLEILE, M. D.,
Prof. Physiology, Ohio State University.

The work here given was undertaken with a view to elucidating the effects of larger quantities of electricity on the organism. Incidentally the value of artificial respiration after death by electricity was also tested. As this is the minor portion of the work this part will be given first.

The data bearing on the subject in general are quite meagre, especially as to the amount of current which actually passed through in fatal cases.

In all my experiments dogs were used, and in the subjoined table the weight, voltage, amperage and time are given for each case.

In the first experiment 525 volts, 2 amperes were applied for 8 seconds; in the second, 220 volts, 1.2 amperes; in the third, 106 volts .4 ampere, 10 seconds; in the fifth, 96 volts, .35 ampere, 2 seconds; in the sixth, 52 volts, .3 ampere for 1, 2 and 4 seconds; in the seventh, 70 volts, .32 ampere, ½, 1 and 2 seseconds was used.

Before the application of the current a canuala was put into the trachea so arranged that it could at once be connected with a bellows for the purpose of giving very complete artificial respiration. Respiration was set up as soon as the current was off and this was continued for periods varying from 20 minutes in the first case to 2½ hours in the last, and in no instance was resuscitation accomplished.

Further work was carried on for the sole object of studying the effect of the current.

Our electrodes consisted of oval copper plates 3 by 2 inches, covered with sponges moistened with salt water. One electrode was applied at the base of the skull, and the other over the middle of the back, the hair of the animal having been previously well moistened with the salt solution. The current used was the alternating current of 130 periods per second. While the details of each experiment are given in the table subjoined, a few are selected for special presentation. The larger voltages were abandoned for 100 volts, 70 and 50, as nearly as could be reached.

Ninety-eight volts with .32 ampere was applied first ½ second, then 1 second with recovery, but in two seconds produced death. Fifty-two volts with .3 ampere was applied 1 second, later 2 seconds, with recovery, then 4 seconds, producing death. Fifty-two volts, .24 ampere applied 3 seconds produced death. Fifty-one volts, .12 ampere, 4 seconds; 51 volts, .18 ampere, 4 seconds was not fatal. Fifty-one volts, .2 ampere, 4 seconds produced death. From these figures and similar ones to be obtained from the table, it is evident that the result depends, somewhat independently of the weight of the animal, on three factors: On the voltage, on the amperage and upon the time of application. A variation of either one of these factors may change the result—that is, a lower voltage with lesser amperage applied for a longer time will have the same effect as a current of higher voltage or more amperage applied for a shorter time. In this connection it was suggested by Professor Thomas that the joules necessary would be found the same in each case, and calculations show that this is approximately true. To prove this absolutely it would, of course, be necessary to work with the minimum quantities as to voltage, amperage and time in each case, and no doubt one or another of these factors will be found in excess in most cases. In these experiments it is of great interest to point out this approximate relation between the results, and the absolute amount of mechanical energy used. The results found on post mortem examination of the animals were so uniform that they can be very briefly described. In all cases this examination was made immediately after death, and at first we wished to study the changes produced upon the heart, so that the incision was made through the chest walls and the heart exposed as rapidly as possible. This organ presented the following peculiar conditions. The left side was completely relaxed, the right side was intensely gorged with blood, as were also the large veins in the immediate vi-

cinity of the heart, and the little appendages of the upper portion of the heart were found beating regularly, strongly and synchronously. Pressure on the heart caused a contraction of the other parts, and from this it was evident the death was not due primarily to the destruction of the heart fibers. In addition it was noted that the deep and extensive cuts made in the tissues were free from blood, and that the arteries were quite small and contracted.

This excluded a direct effect upon the heart, and, having shown by artificial respiration that the stoppage of this function was not the cause of death, other causes were to be looked for.

It was supposed that the current immediately struck the pneumogastric nerve stimulating those fibers which control the heart in that they have the power of arresting its beat, when strongly stimulated. To test this view, resort was had to the hypodermic injection of atropine, the action of which drug is to paralyze the nerve fibers, and thus prevent their action on the heart when stimulated. In one case $1\frac{1}{30}$ grain of atropine was given, 52 volts with .25 ampere was applied first for 2 seconds, then for 4 seconds, and this resulted in death. In a second case $\frac{1}{30}$ grain of atropine was given, 52 volts with .29 ampere was applied first 2 seconds, then 4 seconds, again resulting in death. These animals were not therefore rendered more resistant by the drug, and the theory as to the role of the pneumogastric nerve was abandoned.

I now recall the fact already mentioned, that after death, incisions into the animal are not followed by bleeding, that the arteries are contracted down to a very small caliber, and that the blood is crowded into the very large veins in the trunk. Taking these facts, it was suggested that the current acted upon the arteries through the nervous center which controls their diameter. It is well known that the arteries are supplied with a middle muscular coat in which the fibers are circular, and their contraction would of course cause a narrowing of the artery, rise of the blood pressure, and a consequent impediment of the heart's action; in fact it has been experimentally demonstrated that the arteries can be constricted to such an extent as to produce a rise of blood pressure which the heart is unable to overcome, and that the circulation will stop from this cause. It is further known that we have in the brain, most of the nerve matter whose function it is to control the vaso-motor nerves, the arteries at one time, and in one place contracting and thus decreasing the amount of blood

at another time and in another place, dilating and thus increasing the amount of blood getting to another particular part. To test this view, that the action of the vascular nervous system was the cause of death, we resorted to the hypodermic use of nitroglycerine. It is known of this drug that it powerfully affects the arterial system, causing, when given in larger doses, an extreme dilatation of the arteries, and a consequent great lowering of the blood pressure.

The first animal received $\frac{1}{75}$ of a grain of nitroglycerine and, when the effects were fully established, a current, which was known to be fatal, was thrown in; namely 50 volts, .24 amperes for 4 seconds, but the effects produced by this current soon passed off and there was complete recovery. Then 97 volts, with .54 ampere were thrown in for 1 second but this caused death. In another case $\frac{3}{75}$ of a grain of nitroglycerine was used; here 52 volts, .22 ampere, a fatal dose, were thrown in for 4 seconds with recovery. One hundred and four volts, .6 ampere were thrown in for 4 seconds producing death, but after the current was taken off there was noted 8 deep although irregular respirations. In other cases where the nitroglycerine was used, there was no apparent effect, but some investigation led me to attribute this to the unreliability of the tablets of nitroglycerine used, and this drug was then abandoned for nitrite of amyl, a substance which has the same physiological effects as nitroglycerine but which can be always obtained pure, and the effects of which can be more accurately regulated because it is given by inhalation. In the first case the animal was brought moderately under the influence of the nitrite of amyl, 52 volts with .24 ampere were thrown in for 3 seconds, (this by the way being a fatal dose ordinarily,) without producing death. Fifty-two volts, .25 of an ampere for 4 seconds, also a fatal dose, failed to produce death. Fifty-two volts, .3 of an ampere for 6 seconds produced death, but after the current was taken off, the animal made 22 deep, regular respirations though not a trace of the heart beat could be made out, this incidently proving that stoppage of the respiration is not the primary cause of death.

Three more experiments may be selected. Numbers 24, 26 and 27 of the table.

No. 24 was a pointer dog in excellent condition, weighing 34 lbs. Nitrite of amyl was given until the effects were fully marked. Fifty and five tenths volts with .2 ampere were given

for 3 seconds; after a pause the same quantity was given for 6 seconds, followed by recovery. Three days later the same dog, which showed no effects at all of the previous treatment, was given—without the nitrite of amyl—51 volts, .2 ampere, 4 seconds, producing death.

In the last case a dog weighing only 12 lbs. and of such general condition of weakness that the assistant protested against his use as not being competent to demonstrate anything, was given a full dose of nitrite, then 50 volts with .6 ampere were applied for 4 seconds and followed by recovery. The dose applied for 6 seconds produced death and here again several respirations were noted.

The statements made in regard to the cause of death by electricity are so at variance with one another that it is unnecessary to review them here. Among other plausible reasons it has been stated that the current has a direct disintegrating effect on the brain and nerve tissues and that herein is to be found the cause of the fatality. The disintegrating effects of the current on the brain and nerve tissue said to follow, are not to be seen macroscopically and the microscopic examination of these organs so far as made by us failed to reveal any change in their structure. It would appear therefore that death in electric shock is entirely due to the fact that the current produces a contraction of the arteries through an influence on the nervous system, and that this constriction of the arteries throws in such a mechanical impediment to the flow of the blood as the heart is unable to overcome, and that, where drugs are given to counteract this effect, much larger doses of electricity than the ordinary can be borne. While artificial respiration may be of value in simple stunning, when larger doses have been taken, no rational means of resuscitation have as yet been suggested.

I was enabled to carry out the above experiments by the loan of apparatus kindly furnished by Professor Thomas and was greatly assisted in the work by Mr. Boyd, of the Physical Department who was present at every experiment and who made the measurements for us.

The current was obtained from a surface wound alternator giving an approximate sine-curve. For potentials of 100 volts or less, connection was made with the secondary of a suitable transformer. Potentials of over 100 volts were taken direct from the primary circuit, adjustment being made by varying the generator field.

No.	Weight (lbs.).	Volts.	Amperes.	Time (seconds).	
1	21	525	2	8	Artificial respiration 40 min.—Death.
2	15	220	1.22	8	Artificial respiration 25 min.—Death.
3	30	106	.4	10	Artificial respiration 1 hr. 15 min.—Death.
4	42	98	.4	4	Artificial respiration 2 hrs. 30 min.—Death.
5	27	96	.3	2	Artificial respiration 1 hour.—Death.
6	21½	52	.3	1 2 4	Recovery. Recovery. Death.
7	12	70	.32	.5 1 1. 2	Recovery. Recovery. Recovery. Recovery.
8	40	47.5	.25	4	Death.
9	35	96	.35	1	Death.
10	30	52	.25	2 4	1-30 grain atropine: Recovery. / Death.
11	28	52	.29	2 4	3-60 grain atropine: Recovery. / Death.
12	26	50 97	.24 .54	4 1	1-25 grain nitroglycerine: Recovery. / Death.
13	30	48	.22	4	1-20 grain nitroglycerine.—Death.
14	33	52 104	.22 .6	4 4	4-30 grain nitroglycerine: Recovery. / Death.
15	22	51	.32	4	6-50 grain nitroglycerine.—Death.
16	22	47	.2	4	1-10 grain nitroglycerine.—Death.
17	27	52 106	.2 .55	4 1	1-10 grain nitroglycerine: Recovery. / Death.
18	36	51	.25	4	80 grains chloral, 1-50 grain atropine: Death.
19	30	52	.24	3	Death.
20	51	52	.24 .25 .30	3 4 6	Recovery. Recovery. Death. (22 deep respirations.)
21	25	50.5	.2	3	Death.
22	19	51	.2	3	Small dose nitrite of amyl.—Death.
23	17	51	.2	3	Small dose nitrite.—Death.
24	34	50.5	.2	3 6	Full dose nitrite: Recovery. / Recovery.
25	38	50.5 101	.2 .2 .5	4 6 1	Full dose nitrite: Recovery. / Recovery. / Death.
26	34	51	.12 .18 .2	4 4 4	Recovery. Recovery. Death.
27	12	50	.2	4 6	Full dose nitrite: Recovery. / Death.

Voltages were measured by means of a Weston A. C. voltmeter. The mains supplying the current were of low resistance, so that the drop when the circuit was closed was found to be negligible. The figures given are the actual potential differences of the electrodes, while the current was flowing through the animal, correct to within one-half volt. A Siemens dynamometer was used for measuring the current when the time of contact was less than four seconds. It was somewhat difficult to make a setting, so that readings for those short times can not be taken as correct within five per cent.

Discussion.

Mr. G. W. Blodgett:—I would like to ask the author two or three questions. He speaks of applying a current of 52 volts .3 amperes successively to an animal for six seconds. I would like to know what the interval was between those applications?

Dr. Bleile:—The intervals were never timed, but we would wait until the animal had fully recovered, as evidenced by the general condition, which can be readily told. There is always dilatation of the pupils, and you can wait until that goes down, and then the wagging of the tail is a good index of a dog's condition, if he responds freely by a wag to such gentleness as is used with dogs.

Mr. Blodgett:—Would there be an interval of a few seconds?

Dr. Bleile:—Oh it was more than a few seconds. It was from five to ten or fifteen minutes.

Mr. Blodgett:—So that in the second application there could be no effects remaining from any other application?

Dr. Bleile:—No, sir, that is excluded. In fact in this one case, that of the pointer dog, case No. 24, that dog was unloosed immediately after the current was off, it taking just a half minute to unloose him, and he was quite playful and entered into some little sport in that short time after.

Mr. Blodgett:—I have a curiosity to ask one other question, because I am not a medical man. You speak of putting an animal "moderately" under the influence of nitrite of amyl. I would like to ask what the effects of that drug are when used moderately, as in this case, or freely, in other cases. What are the effects which the drug itself would produce?

Dr. Bleile:—The effect would be ascertained by feeling the pulse. The pulse has a certain amount of hardness, and a certain character, which is due to the elasticity of the arterial walls. When the artery dilates, that elasticity is changed, and the charac-

ter of the pulse wave is changed. It comes up slower, and at the same time there is an increase in the number of heart beats. You will always find that when the blood pressure falls, there is present an increase of the beat, and *vice versa*, there is a compensatory effect. That was, of course, a matter that was merely estimated. We had no means of gauging that; but when we found just a perceptible impression on the character of the pulse and the frequency, I call that "moderate;" and when it was pushed a little, that I call a full dose. It produces in man a great flushing of the face and giddiness.

PROF. JOHN C. SHEDD:—I would like to inquire what means were taken to secure the variation of amperage where the voltage remained the same. I notice in experiment No. 20 the voltage was 52. The amperage in one case was .24 to .25 and .30.

DR. BLEILE:—In those cases the variation was due to the moving of the electrodes. The animal did not remain perfectly quiet, and accordingly as we got greater or less contact the amperage would correspond.

MR. JULES NEHER:—I would like to touch upon the same question. It is natural for electricians to study the relations between amperes and volts. I note that in most of these cases the resistance of the animal is very much the same. In the case of 50 volts and .24 amperes it would be about 200 ohms; except for the last animal Dr. Bleile speaks of, a 12 lb. dog which showed the exceedingly low resistance of 80 ohms, the current being 50 volts and .6 amperes.

DR. BLEILE:— No. 27?

MR. NEHER:—I think it is No. 27; 50 volts and .6 ampere were carried over four seconds, and then six seconds with the deadly effect—I see now that I made a mistake. I understood it was .6 ampere. I see now it is .2 on the table. I have frequently been told by persons who seemed to know something about it that the current when applied would rise during the application in some way, as if it would find a better path after having been applied for short periods, and I wonder if in these experiments the same phenomena was proved in longer duration.

DR. BLEILE:—We did not find that, so far as these experiments went. I think that statement has been made in regard to man, and it can be explained in this way. When the current is on, it will in most instances produce a secretion of sweat, and by moistening the skin you get a better conduction, and therefore a rise.

PROF. ELIHU THOMSON:—This valuable paper of Dr. Bleile's reminds one of some matters that were investigated some time ago by the late Dr. Tatum. He carried out his experiments with the idea of discovering the effect of different frequencies in producing physiological effects. As I recall his results, he found that at a certain frequency, which I think was very nearly 60 periods per second, the maximum physiological effect was produced, measuring the current that was passed through the animal. He

used dogs, I believe, in his experiments. and also the human subject, discovering the limit of endurance or the amount of current which could be passed through the body and sustained without very great discomfort. He found also that as the periodicity rose up to, I think, some 2,500 periods, the immunity from harm by the passage of the current became very much increased; and, if I remember the figures, at about 2,500 periods he passed through the brain of a dog some .34 ampere without any particular effect. I may be mistaken about the figure, however. But it was certainly as large a current, or larger, than that which would seem to be necessarily fatal if of low frequency. It is well understood too, now-a-days, that as we get the frequency still higher, a very considerable current value, if we read the values by the calorific effects, can be sustained by the organism without any apparent injury; so much so that a current which would apparently be large enough to be represented in its calorific effect, by, say an ampere and a half, can be readily sustained by the human subject.

Now, as to the equivalence alluded to in the paper of a variation of the factors of time of application and amperes applied, of course there must be a limit to such a relation. There must be a certain current which can be sustained almost indefinitely, as we well know. We take hold of the terminals of an electric apparatus, and with a certain current we can hold indefinitely, and of course we will have the delivery of energy at a certain rate; piling up, as it were, in the system; so that we must have a lower limit at which the relationship referred to will not hold good. There is another fact which I think may have some influence on the results. That is the question of education of the system to stand the current. I remember some experiments were made several years ago by some of our young men in the Thomson-Houston Company for the purpose of determining what alternating current or voltage they could stand. They began low and gradually worked up, catching hold, of course, of the wires, using the hands They found that beginning at, say 50 volts and increasing the voltage, they could take shocks of 450 volts alternating current, at which point they had to desist. It made them sick for the afternoon, but no other harmful results followed. Of course a very severe shock was received. Whether the system could have stood such an application at once is questionable. I think very likely the shock might have been fatal; but by gradually, as it were, bringing on the power of resistance, somewhat in the same manner that power of resistance to the action of drugs may be brought on by the administration of small doses at first, then larger and larger doses, the system seems to have the power of setting itself against adverse influences providing it is given time.

An interesting question arises in connection with the results given in the paper in regard to high frequency. I have in mind having seen the statement published some time since in regard

to the effects of high frequency currents passed through the animal system, that a very great relaxation of the arterial and capillary systems takes place; that such is in fact the effect of the passage of high frequency currents; that a wound made after the passage of high frequency currents bleeds very freely. If that be the case, then we have the interesting speculation as to whether instead of administering nitroglycerine or nitrite of amyl we should not administer high frequency currents and relax the whole arterial system, and thereby cause instant recovery. I merely throw this out as a suggestion, a field for work that might produce valuable fruit, or might not.

MR. NEHER:—The discussion thus far has been on the effects of alternating currents on the animal body. I wonder if anybody can inform us of the effects of direct currents. It has often been suggested that direct currents would have a more severe influence on animal life, owing to the powerful electrolytic effect produced either in the nerves or in the system of the blood vessels. It is understood, I think, that with a high potential direct current, shocks were usually sustained by getting in contact with an arc circuit. There I suppose that the potentials rise to enormous values the moment the circuit is broken, and that death is probably due to the very high potential. There may be some person that can tell us what happens with comparatively low direct current voltages as they are in use on railway circuits.

MR. GARRATT:—I notice a little error here that should be corrected. On page 513, in the middle of the third paragraph, it says: "In one case $1\frac{1}{10}$ grain of atropine was given" Evidently that should be $\frac{1}{10}$ grain instead of $1\frac{1}{10}$, as that would have been fatal anyway without any electric current.

In regard to death from direct current, none of us can give the answer desired, because none of us has been killed yet, but I saw a man come very near it once with a current impressed by about 750 volts. It could not have been much more than that, and how much less I cannot state, because I do not know what the resistance of his body was. The conditions were these: A large storage battery had been placed in series for the purpose of testing, and I had the terminals of the system in my hand, both hands wet with the weak sulphuric acid solution, giving very good contact; and one of those inquisitive individuals who are constantly opening and shutting switches to see what will happen, pulled down the main switch which was located in an adjoining room of humble name but undoubted utility, and left me in the circuit. I was knocked insensible. Some one who happened to be near by pulled me off the circuit, and I came to. I will not take the time of the INSTITUTE in describing my feelings. In fact I do not think I am adequate to it this morning. But it was a case of severe shock producing insensibility by a pressure of something like 750 volts; my hands were not badly burned. Two or three times in my experience I have got afoul of arc light currents.

I remember not long ago doing one of those foolish things which some of us will do sometimes. I was standing at a T.-H. arc machine adjusting the brushes on the right side and happened to notice the oil cup dripping into the air-blast was not feeding, and instantly I reached over to adjust the oil cup with one hand and held onto the brush with the other, and was brought directly across the circuit. It was a shunt across the 20-light machine, with, I think, 18 lights burning at the time. It did not produce insensibility. So the storage battery current at a comparatively low voltage does produce a more serious effect, or it did in my case, than the kick that follows from an arc light machine, though, of course, the contact was not so good in the latter case. There is a question I should like to ask Dr. Bleile. Is a fatal shock produced by a momentary contact either with a direct or an alternating current, from the effect upon the pneumogastric nerve, preventing heart action from going on, although none of the nervous or muscular mechanism is destroyed? Is death produced by a shock which does not destroy any of the nerve or muscular fibre?

DR. BLEILE:—We have what is known as surgical shock. That is a term familiar to all of you. The pneumogastric nerve is a little peculiar in its action, as I have already mentioned, and it is particularly susceptible to so-called reflex stimulation, or excitation. For example, some of us, I dare say, have run through buildings in course of construction and fallen through and struck a joist, and had "that tired feeling" known as fainting. That fainting feeling is due to momentary suspension of heart action through a reflex effect coming by means of the pneumogastric nerve, the bundle of nerves through there being in pretty direct communication. Then we have another set of nerves connected with the teeth, branches of the fifth pair, and that accounts for the deaths that often occur in the dental chair. A tooth is extracted and that produces a powerful impression on this nerve, which passes back to the medulla, is reflected over on the pneumogastric nerve, and stops the heart. The same thing occurs sometimes when people fall dead on the receipt of sudden news producing a violent emotion, either pleasant news or news that is unpleasant. Fainting is not uncommon under such circumstances, and deaths have been reported. Now, all that comes from this reflex effect on the pneumogastric; and I think in man another effect comes in, namely, the physical factor, something which exists only to a very slight extent with the lower animals. Then I think some people are scared to death in just this way, through fright.

PROF. ANTHONY:—I should like to ask a question. I confess to no knowledge on the subject myself. In regard to the effect of the high frequency current, is it certain that the current does pass through the body? When we have a high frequency, does the current that we have in the conductors outside, go through the

body, or does the body act as a sort of condenser. If the current gets into the surface, or into the electrodes perhaps, and really does not go through, then we really do not get as much energy in the body as is represented by the current that passes through the wire. Under certain conditions—and it does not take a very large condenser either—we could have a condenser effect such that there was no current whatever passing through the circuit, the energy simply going into one side and out again. May not the human body act in something the same way with these very high frequencies.

PROF. THOMSON:—I think I can answer the question. I particularly arranged an apparatus to discover whether the action of the body as a condenser had much to do with the phenomena. To dispose of the action of the body as a condenser we may imagine this condition of things: a person on the other side connected with the other terminal, and an incandescent lamp between. If their capacities are nearly the same, as they would be, then that incandescent lamp should not light if the current does not pass through the body. But the incandescent lamp does light, and lights just the same, and with the same intensity as if it were interposed between one person and a terminal and the hands were joined, having the same brilliancy under the same conditions. That indicates, of course, that the current which carries energy does pass through the body. Another way in which the same indication may be arrived at. If the body be supposed to act as a condenser, how about the arm that receives the discharge? The arm is not the condenser. It must act as the conductor to a condenser, and it is possible to take sparks that will melt wire, that will light incandescent lamps to a very high brilliancy, through the arm without producing any sensation in the arm. Furthermore if the current travels through the body by being confined to the surface, then if the nerve sensibility is more active at the surface, we certainly should have more effect at the surface, unless there is some peculiar direction of flow which prevents the carriage of the impression to the nervous organism. But if you take hold of a handle of limited surface, if, for example, a metal tube be held in the hand as an electrode, and crowd the current to a point at which you will feel a decided stinging sensation, you do not feel that current around the edges of the contact, but you feel it all over the section, the current is entering throughout the section of the skin exposed to the metal. This indicates that the current does penetrate into the tissues, and passes right through the nerves of sensation also; but it requires a very considerable density to excite them. One can carry quite enough current to light an incandescent lamp through the little finger, as I have tried. I have put a ring around the little finger and lighted an incandescent lamp by current passing through the finger. The contact surface was very sensitive, but the current passed did not harm the finger. One could feel the sensation of

warmth throughout the finger, and not alone on the surface of the finger either; apparently deep seated. I could not say whether the impression was exact or not, but so far as one can judge it is deep seated, especially at the knuckles, where there are large bones producing resistance. Furthermore, if you dip your hands into brine up to about the wrist and take a heavy, high frequency current through the body, the concentration of heat at the wrist is very noticeable. One feels a warmth not at the surface, or as though the current passed on the outside skin, but right in at the bones, interiorly, apparently, where the current crosses the joint tissues. I think there are plenty of instances that I might cite which indicate that we do not have here simply condenser action, but a real conduction of current. Another thing. I constructed boxes filled with damp sawdust to take the place of the body, so as to have them on hand, supposing that I might need them. It was not always convenient to have human subjects around. I arranged the apparatus (boxes of sawdust slightly dampened with weak brine) with metal plates for electrodes that could be introduced deeply into the sawdust anywhere at all. I found on making the test that I could get indications of current flowing anywhere between the plates by introducing insulated electrodes deeply into the sawdust. Furthermore, I replaced the sawdust boxes without otherwise changing the conditions, making the conditions absolutely identical in all other respects, by water rheostats, and measured the elevation of temperature in those rheostats during a certain interval of time, and I found that with the water rheostats replacing the sawdust box, under equal conditions (and that is about the only way we can deal with these currents), a horse-power of energy was delivered to the water rheostat; that is, the energy was delivered at the rate of a horse-power, and that energy must have been delivered to the body under similar conditions at the rate of a horse power. Now, I hardly think that such an amount of energy could have been given to it by a condenser action. It must have been by some other action, resistance of the body opposing the current, So I think, when we look closely into this matter, and take all these considerations together, we have ample proof that there is an actual passage of a considerable current through the tissues of the body; perhaps not evenly distributed, perhaps following the channels nearer the surface, perhaps following the blood streams, depending, of course, upon the local conditions.

MR. BLODGETT:—Prof. Anthony asked and Prof. Thomson has answered the very question that came into my mind, whether the current was confined to the surface or whether it actually passed through the tissues of the body. In Prof. Thomson's experiment where he immersed his hand in salt water, and observed the sensation at the wrist, it would seem to me that if the current was strong enough to produce a sensation there, it should have produced it through the whole section of the arm, or, at least, at the

joints, where there might have been a greater resistance, or for some other reason the sensibility might be greater. I would like to ask whether he did discover any sensation above the point where it was immersed in the salt water.

PROF. THOMSON:—The particular sensation that attracted my attention at the time, was at the wrist in that experiment, and I explain it by the fact that the section farther up is continually increasing, while at the wrist there is probably a minimum of tissue. The bony mass there is the major part of the section, whereas above the elbow there is a much greater mass of muscular and other tissues which would be full of conducting fluid also. I did, however, on still further pressing the experiments by immersing the wrist,—seeing that the wrist was the resistance in circuit,—try to get rid of resistance in circuit and reduce it still more by putting a portion of the forearm into the brine. Then the sensation of heat at the wrist stopped, and the sensation of heat was transferred to the forearm just above the brine. There is undoubtedly a peculiarity noticeable in these cases, that the heat sensation is just above the line of entrance of the current; at least it appears so; although in the case of passing current through the little finger, the heat sensation appeared to be throughout the finger and at the joints. It is difficult, of course, to locate so indefinite a sensation. It naturally is graded off in both directions, and all you can say is, "it is about here."

MR. WALTER E. HARRINGTON:—I would like to ask Dr. Bleile if he can explain a certain action that the electric current has on crabs. I made some tests on crabs a few years ago with a 500-volt direct current; took a lamp circuit, five 16 C. P. lamps in series, and placed one terminal of the circuit on the crab's back, and then touched each one of its fingers or legs,—I do not know what you would call them—and as I touched them they would throw them off; throw them away several inches. I did that with half-a-dozen different crabs, and never have been able to find out the cause, or the reason, the crab would do that.

DR. BLEILE:—Did I understand you to say it cast off the legs?

MR. HARRINGTON:—Yes, throw them several inches.

DR. BLEILE:—Five hundred volts?

MR. HARRINGTON:—Yes.

DR. BLEILE:—A very violent contraction will have that power, or at least there is the ability to throw off members by a violent contraction of the membranes, and you get excessive muscular contraction there, enough to throw them off.

PROF. THOMSON:—I might remark in this connection that I have understood that whenever another crab gets hold of a leg firmly and won't let go, the first one throws off the leg, and the particular crab in question may have thought that the 500-volt current he got was another crab.

MR. BLODGETT:—I recall certain lectures on zoology to which

I listened a good many years ago, on a certain form of land spider that has that same faculty, namely the ability to throw off its legs; if you pick one up in your hand, it is liable suddenly to drop off one leg after another until it wriggles out of your hand with a spherical body and no attachments whatever, and presently it grows a new set of legs at his convenience.

MR. HARRY ALEXANDER:—On one occasion I was testing a motor, 500 volts, and remember distinctly that the voltmeter read 570 volts. We had a Weston ammeter there, with both binding posts on one side, and we had a single pole switch for short-circuit in the ammeter. At the time I thought I had short-circuited the ammeter, and although the motor was being tested, I at once unscrewed the leads to place them on an instrument of smaller degrees. I took the lead leading to the binding post, unscrewed the binding post and pulled it apart. I received a terrific shock, and should say held on to it for quite some time, but convulsively I let go of it, and as I let go of it, my finger that had hold of the thumb screw of the ammeter blistered up quite perceptibly. The way I was affected by the shock was that for almost an entire week I was taken with severe vomiting spells as well as convulsions, generally in the evening before retiring. I called in the doctor, but he did not attribute it to the shock. He said, if I had ever got the shock of that voltage by unscrewing the ammeter, I would have been dead long ago. He said I was suffering from a cold and had disarranged my stomach. So I should like to have Doctor explain the effect it had upon me, if possible.

PROF. CROCKER:—I know that I speak the sentiments of the INSTITUTE in acknowledging our great indebtedness to Dr. Bleile for this interesting and able paper. It would have been to his own interest to present it to some medical journal, but our interest in this subject is so great, that we appreciate it highly. I therefore move a vote of thanks to Dr. Bleile for his important paper.

[The President put the question on the adoption of the motion, and it was determined in the affirmative.]

The Secretary announced that the Cataract Construction Company had donated to the members of the INSTITUTE in attendance at the meeting, copies of the Niagara edition of *Cassier's Magazine*, which would be distributed later.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th 1895, President Duncan in the Chair.

LONG DISTANCE TRANSMISSION AT 10,000 VOLTS.

(The Pomona Plant.)

BY GEORGE HERBERT WINSLOW.

The Pomona plant was installed in the summer and fall of 1892 for the San Antonio Light and Power Company, of Pomona, Cal. It was increased in the following spring, and early last year the capacity of the plant was doubled by duplicating the entire equipment. At the present time, when the plant has been in regular operation for more than two years, and its complete success has established confidence in the successful outcome of many similar projects of greater magnitude, it seems fitting to present a careful description of the entire installation. The electric plant was installed under the personal direction of the writer, as electrical engineer, who presents many of his personal observations on its construction and operation.

The plant is used to transmit energy from a waterfall to substations at Pomona, 13¾ miles distant, and San Bernardino, 28¼ miles distant, from which points it is distributed for incandescent and arc lighting. It consists of a Pelton water power plant and a Westinghouse alternating current transmission plant in which generators supply currents to sets of raising and lowering transformers operating at 10,000 volts, and delivering current to the local circuits at 1,000 volts.

The water power for this plant is derived from the San Antonio creek, which is chiefly supplied by the melting snows and the rains on San Antonio Mountain. Side canyons, however, also furnish some water. The creek flows for several miles through a narrow valley at the upper end of the San Antonio canyon in a bed which it has washed for itself in the layer of

boulders and gravel formed by the action of an immensely larger stream in past ages.

At the lower end of the valley, a sharp ridge extends eastward from the side of a neighboring mountain, from which it originally split off, and blocks up the valley except at a narrow place at which bed-rock is exposed, and through which the stream plunges suddenly downward at least 90 feet between precipitous walls of rock, forming the San Antonio Falls.

To utilize this fall, part of the water is diverted by a dam about 200 feet above the falls into a canal which conducts the water to a tunnel passing through the ridge. At the other end of this tunnel, the water enters a large pipe leading to the power-house, which is located 412 feet below the level of the outlet of the tunnel.

Pipe-Line.

A vertical projection of the pipe-line, giving the sizes of the pipe, is shown in Fig. 1.

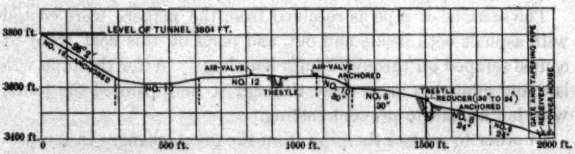

Fig. 1.—Pipe Line, Pomona Plant. Effective Head 390 feet.

The pipe is of sheet steel, double-riveted throughout, and was delivered on the ground in sections having a length of 11 feet 6 inches. These sections consist of four sheets, each three feet long.

The diameter of the pipe up to within 450 feet of the power-house is 30″, with the exception of the length which connects it to the sand-box at the top of the pipe, which length is considerably expanded, so as to allow the water to flow slower on entering, and thus to reduce the entrainment of air. Near the power-house a "reducer" is inserted in the pipe to reduce the diameter to 24″, and this size is maintained from this point to the power-house. The pipe was designed to carry 2000 miner's inches of water (measured under a head of 6 inches), without unnecessary loss by friction. The capacity is equivalent to 50 cubic feet per second, or 1882 H.P. at 390 feet effective head, assuming

a wheel-efficiency of 85 per cent. This is nearly three times the power for which the present station was built, but the extra capacity of 1000 horse-power obtained by increasing the capacity of the pipe costs so little when compared with the cost of building an entire new pipe line, that it is much more profitable to lay the larger pipe in the first place, if sufficient water can ultimately be developed to utilize the added capacity.

The thickness of the pipe is increased as it nears the power-house to provide for the increase in pressure in the lower parts. At the first bend it is made greater than that of the sections above it on either side, because the pressure on it there is greater. After passing the second air-valve, first No. 10 and then No. 8 steel is used, the latter size being continued to within a short distance of the power-house. The last few lengths are of No. 6 steel.

The horizontal distance between the mouth of the tunnel and the power-house is 1940 feet, and the difference in level between the tunnel and the floor of the power-house is 412 feet. The total length of the pipe is 2370 feet.

The sections of pipe as received from the makers were coated with asphalt both inside and out, and parts of this coat were of course scraped off through rough handling. After the pipe was laid and jointed, a man went through it and painted the joints with hot asphalt to prevent rusting.

In order to protect the pipe from the great changes in temperature which occur in the mountains between midday and midnight, earth and loose rock were placed around and on top of the pipe without any tamping, and where enough earth could not be conveniently obtained, brush was cut and piled on the pipe and covered with a light layer of earth and rock.

The lower end of the pipe is closed by means of a 24 in. Ludlow gate-valve, which is bolted to a cast-iron flange riveted to the end of the pipe.

The stem of the valve is geared to a small hand-wheel, partly on account of its weight, but chiefly in order that the gate may not be shut too quickly, as otherwise the pipe would be subjected to severe strains, resulting from suddenly checking the velocity of the column of water. For use under heavy pressures the gearing is also necessary in order to be able to move the valve at all. The head of water on this plant is so great that it is impossible to open the valve while the pipe is full, and the receiver empty. It is therefore necessary to equalize the pressure by filling the receiver through a by-pass, or to partially empty the

pipe by means of a relief-valve attached to the pipe close to the gate. The relief-valve is primarily designed to protect the pipe from shock by allowing the escape of a considerable quantity of water in case of an increase of pressure in the pipe; such, for example, as would occur should any obstruction partially close the opening of the gate. It has a circular valve so proportioned that a slight movement of it will afford a large opening for discharge. The valve is held in place by a weighted lever, and is set so that a very slight increase above normal pressure will cause it to open.

The gate is connected by a tapering pipe of steel to a horizontal, cylindrical steel receiver 20 feet long and 42″ inside diameter, from which the water is distributed to the wheels. The object of such a large receiver is to avoid the loss in head which would be occasioned by the eddies formed when drawing the water from the side of a smaller pipe. It also serves to keep air from being drawn into the discharge pipes in case it accumulates in the receiver. (Last year the receiver was lengthened to 48 feet.) An air-valve is placed at the top of the receiver. Two tapering cast-iron pipes (a large and small one) are bolted to the lower side of the receiver at an angle of 30 degrees.

Water-Wheels.

The above pipes conduct the water from the receiver to the under sides of two independent Pelton water wheels, which drive an alternating current generator and its exciter.

To the end of each pipe is attached a Ludlow gate-valve, the stem of which passes horizontally into the dynamo room through a bushing in the concrete wall. The larger of the two stems is geared to a hand-wheel; the other is fastened directly to a smaller hand-wheel. The flow from each pipe can thus be completely controlled from the dynamo room. The pipe running to the generator wheel is provided below its valve with two nozzles cast in one piece, and attached to the valve by means of a limited ball-and-socket joint, which permits them to be moved vertically to to deflect the water. (See Fig. 2.)

The pipe supplying the exciter wheel has below its gate a throttle-valve, the stem of which passes through the wall into the dynamo room, where it can be connected to a governor. The wheels are located directly below the receiver, and above a race-way which conducts away the water after it drops from the wheels.

The speed of a Pelton wheel is dependent for a given load and head of water upon the amount of water striking the wheel,

and therefore to maintain a constant speed this amount must be changed every time the load changes, and in proportion to the latter. In the case of the generator-wheel this change is produced by deflecting the water. Constant-speed regulation may also be obtained by throttling the water, as is done in the case of the exciter-wheel. When the water is throttled there is loss in efficiency due partly to the scattering of the water as it flows from an aperture which it no longer completely fills (which causes much water to miss the buckets), and partly to the loss of head caused by friction in passing through the valve. With the deflecting nozzle there is no loss of efficiency due to this cause. There

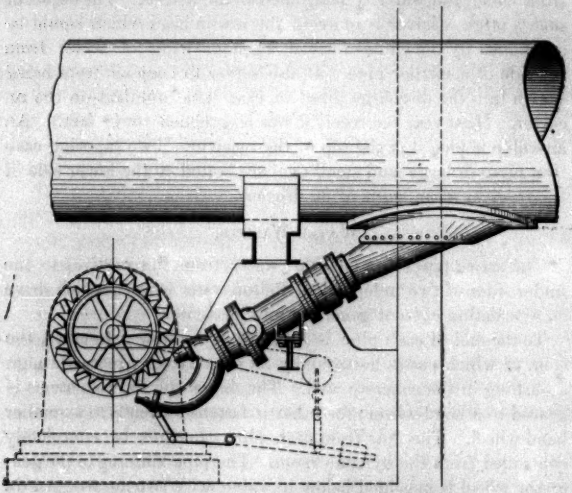

FIG. 2.—Pelton Water-wheel with Deflecting Nozzle.

is, however, a great waste of water at light loads, since under a constant head the same quantity of water must be disposed of at all loads, and for light loads the greater part of it is wasted. To avoid this loss the use of a reservoir naturally suggests itself. It is an unfortunate fact, however, that high heads are confined to mountainous countries and that there a reservoir usually necessitates a high and consequently costly dam. The necessity of building a dam to withstand freshets so increases its cost as to make

the use of a reservoir commercially impossible with high heads. Therefore, the water must continue to be wasted, and the chief apparent objection to deflecting nozzles is seen to be of no importance.

A set of tips of different diameters is supplied with each nozzle, so that the size of the jet used may correspond to the maximum load, and thus unnecessary waste of water be avoided. The tips for the generator-wheel range from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter, while those for the exciter are from $\frac{7}{16}$ to $\frac{3}{4}$ inch. When tips are used of the proper size for the full load there is no need of throttling at the full load, and, therefore, no loss from this cause; and with the deflecting nozzle there is no waste of water at full load, so that for full load the two arrangements are equally good. This is not, however, the normal condition of operation of a lighting plant, for in such a plant each dynamo is driven by a separate wheel, and the load is constantly changing, so that here the deflecting nozzle has the advantage. The deflecting nozzle is also to be preferred under high heads, to avoid the risk of straining the pipe by suddenly checking the flow of water, as would be necessary with a throttle valve if the entire load were suddenly thrown off.

Regulation by throttling is, therefore, only advisable in cases where the head is not excessive, and where the quantity of water obtainable is limited, as is the case where it has to be stored in, and supplied from reservoirs, or when the supply is liable to sudden stoppage. The writer recalls instances of its value in cases which occurred while he was at Bodie, Cal., in the fall of 1893. There the water was conducted 4,700 feet in an open ditch to the pipe, and was delivered by the pipe under 350 feet head to drive an electric generator for a 12-mile synchronous power transmission. In cold weather anchor-ice would form and suddenly block up the ditch at some curve, and the water-pressure would begin to fall slowly, owing to the gradual emptying of the pipe, which could no longer be kept full by the diminished flow from the lower end of the ditch, which now acted as a reservoir. Having throttle valves in the nozzles, however, very little water was wasted, and the plant was thus kept running until the ditch was cleared, whereas with a deflecting nozzle the pipe would have been quickly emptied, even if the gate-valves had been used as throttling valves (which is feasible if the load only varies slightly). Sometimes the head became so low that it

was necessary to throw off part of the load and to run at reduced speed, to keep the motor in synchronism.

Governor.

As already stated, the speed of the generator-wheel is maintained constant for different loads by deflecting the stream. This is done by raising or lowering the deflecting nozzles from the the dynamo-room by means of a lever fixed to a shaft which passes through the wall. The position of the nozzles is controlled automatically by means of the Pelton differential governor. The ability of this governor to keep the generator at a practically constant speed depends on the governor being driven at a constant

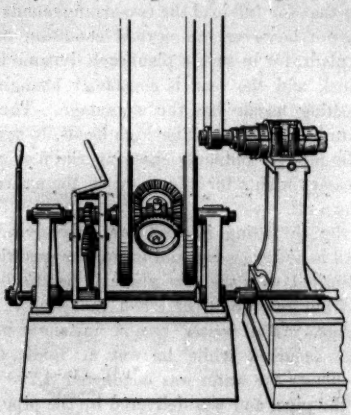

Fig. 3.—Water-Wheel Governor.

speed. I say *practically* constant, for there must be *some* change in speed before the governor can act, and then an appreciable time is required for this action to produce its effect. The constant driving-speed in the present case is furnished by the exciter-wheel shaft. The arrangement for governing is briefly as follows: The generator is geared to stop itself by turning the water off the wheel, and the source of constant speed is geared to speed up the generator by a contrary action. These two actions neutralize each other when the generator-speed is the same as the fixed speed, but when either preponderates the difference acts. Thus an increase in generator speed will act to stop the generator, while a decrease, by making the fixed speed predominant, acts

to speed up the generator. The governor consists, in part, of two similar miter-wheels which are mounted upon pulleys and placed face to face, loosely, upon a horizontal shaft, and are driven at equal speeds in opposite directions, one by the generator shaft, and the other by the exciter shaft. The speed of the pulleys is 200 R. P. M. In Fig. 3 it will be seen that between these wheels, and at right angles to the supporting shaft, there is fixed to the latter a cross-bar carrying two miter-wheels, one at each end, which mesh with the two oppositely-revolving miter-wheels first mentioned. The result is that as long as the two outside wheels are revolving at the same speed the two central wheels will merely revolve upon their axes without tending to move in either direction the bar upon which they rotate. Now, if the generator-speed increases, the corresponding side of each central wheel will have to travel faster forward than the other side travels backward, and the difference between these two movements will result in a movement of the central wheels in the direction of the faster wheel, and the cross-bar will consequently move the same way. The shaft to which the cross-bar is attached will, of course, turn with it, and as this shaft carries a pinion meshing in a toothed quadrant connected to the lever which controls the nozzles, the stream will be pulled away from the wheel until the generator speed falls to its normal value. This point is quickly reached with a full load, owing to the drag of the load, but for a light load the inertia of the armature and wheel prevents them from responding so readily, and the governor does not act quite so quickly. Consequently the generator is not only brought to its proper speed but is carried slightly above it, which causes the governor to reverse, and thus sets up a slight and regular *see-sawing* in the speed. This see-sawing will be increased if there is any lost motion in the governor and its connections. It will also be increased because for a full head and light load the jets only impinge slightly on the buckets, and, since the jets are round, and their upper edges alone strike the buckets (which are themselves curved in the opposite direction) a slight movement of the governor produces a much greater change in the speed of the wheel under light loads than when the whole of each jet is in use. This effect of the jets is more marked when the governor is working to cut down the speed than when it is increasing the speed, because *withdrawing* the jets a given distance causes a greater change in the quantity of water striking the buckets than would be caused

by *advancing* them an equal distance. The see-sawing will be further increased if the nozzles are not fully counter-balanced, as they would then tend to fall away from the wheel.

In order to avoid see-sawing it is the practice in this plant to reduce the head every morning during the light load. This was at first done by opening the extra 4″ relief-valve and allowing water to escape until the pressure had gone down to that corresponding to the desired head. The valve was then set tentatively until the pressure became nearly constant, when the final adjustment was made by partly closing the valve on the generator-wheel pipe. It was afterward found that the working pressure of the water at the nozzle could be sufficiently reduced by the last mentioned valve without also reducing the quantity of water in the pipe, and therefore the relief valves are no longer used for this purpose. In either case the governor throws more and more of the stream onto the wheel to compensate for the decrease in head, and the see-sawing stops. Where a double deflecting nozzle is used, it would seem advisable to have in the upper branch a throttle valve so connected to the deflecting levers that when running under light load the valve would be entirely closed and the regulation be attained by deflecting the open nozzle. When the whole stream of this nozzle had came into use and more water was required, the valve would be opened. In this way the water would be used during light load under more favorable conditions than obtain with a simple deflecting nozzle, see-sawing would be avoided, and in case the supply of water became less, either suddenly, as by a sharp freeze, or gradually, because of diminished rainfall, the water would be used most economically and efficiently during the time of maximum load, which is the critical time. The effect of such an arrangement of the nozzles and valves would be to increase the capacity of the plant for a given minimum water supply, the period of minimum supply being precisely that in which all possible economies are of value. It may be objected that tips of such a size should be used as would bring both streams into full use during maximum load, and that then no valves would be required, but against this is the fact that the maximum load (particularly in a lighting plant) does not reach the same value every night and that it is, therefore, always necessary to use tips large enough to meet the possible demand of any night.

In order to avoid breaking the teeth of the quadrant in case the governor should continue to act after it has moved the nozzles

to either their highest or their lowest point, the pinion on the governor shaft is mounted loosely between two laterally movable toothed ratchets which normally hold it in a fixed position. When the quadrant reaches either of its extreme positions, one of these ratchets will be disengaged by an adjustable lug on the corresponding side and end of the quadrant, and will thus allow the pinion to stop, though the shaft continues to turn. Both ratchets may be instantly disengaged by hand, and the position of the nozzles be regulated by a hand-lever when starting up, or in case of accident to belts or of decrease in head of water.

To start the plant, the governor ratchets are first disengaged, and the exciter is brought to a moderate speed; the generator is then started and its field is charged; it is then brought to about three-fourths of its full speed, and the speed of the exciter is then slowly increased until the cross-bar on the governor ceases to move. At this moment the ratchets are thrown in, and the governor takes charge of the generator-speed. The speed of the exciter is now slowly increased to its full value, which of course brings the generator to full speed.

The speed of the exciter-wheel is regulated by a small throttle-valve, the changes in the position of which do not have any noticeable effect on the pressure in the pipe, owing to the small size of the jet controlled. This valve is so made as to have an equal pressure on each side of its axis when partly open, and hence can be moved from one position to another with little effort, which makes it of special value for use with automatic governors. When tightly closed, however, the areas subjected to pressure are no longer equal, and the valve sticks tightly.

An effort was made to automatically govern the exciter by means of a ball governor driven by a belt from the exciter-wheel shaft, and actuating the valve by means of two leather friction-cones acting alternately on a beveled disk geared to the valve, but this proved unsatisfactory and was finally discarded, chiefly on account of the difficulty of maintaining the proper adjustment, by reason of the wearing away of the cones and of their swelling from dampness. The exciter was therefore controlled directly by hand for a long time. At present the valve is worked from a distance by a simple electrical arrangement devised by Mr. Imlay, in which advantage is taken of the fact that when the exciter is at full speed the movements of the valve necessary to regulate the speed are small.

The device consists essentially of two fixed solenoids in series, energized by current from the exciter, and normally acting with equal force on two iron cores supported respectively at the opposite ends of a walking beam connected by levers to the valve, their normal function being to keep the valve stationary. Either of the coils may be short-circuited at will, by means of a relay controlled by two keys and likewise actuated by current from the exciter. When either coil is short-circuited, it ceases to hold its core, and the core on the other end of the walking-beam is pulled down by its own coil, thereby turning the valve in a corresponding direction. In order that this movement may not be too rapid the coils and cores are immersed in oil, which causes the coils to act as dash-pots to the cores; by this means the movement of the valve may be made as slight as is desired.

The relay is not really necessary, but was used to break the circuit in experiments made before the plan of short-circuiting one coil was devised, and has been retained because very convenient. A momentary closing of either key suffices to correct any change of speed, such changes being indicated by the compensating voltmeter. The current in the coils is reduced by a resistance in series with them about equal to that of one coil, and the current for the relay is shunted from the resistance at about two volts. The current normally passing through the coils and resistance, is about two amperes at 100 volts (about $\frac{1}{4}$ H. P.) and when one coil is short-circuited the current in the other increases to three amperes, so that the maximum power used is $\frac{3}{8}$ H. P.

Power-House.

The power-house is 66 ft. long by 30 ft. wide, and has walls 12½ ft. high. The walls, which are of concrete, were all built by tamping concrete in a space between temporary wooden walls forming a mould, a few feet of wall being built at a time and the planks then loosened and raised to the height of the next section, the walls being thus made at the least expense for timber. The best English Portland cement was used. The walls were consolidated and cement saved by the use of well-washed fragments of rock imbedded in the concrete. In order to obtain the greatest available fall, the power-house was placed as far as possible below the level of the fall. This necessitated blasting into the side of the hill so far that the entire wall next the hill was below the level of the adjoining rock.

The station was built to accommodate four 120 K.W. 7,200 alternation, 12-pole, single-phase Westinghouse alternators, with their full complements of raising-transformers and switchboard apparatus, and two exciters. The first installation consisted of one generator with one 90 ampere 125 volt "1" exciter, capable of exciting the four alternators, and of 240 K.W. capacity of oil transformers in 40 units of 6 K.W., 21 of these being located at the power-house.

Transformers.

Several different methods of connecting the raising and lowering transformers were given careful consideration, the test of actual use favoring a series connection for both primary and secondary coils of both sets of transformers, a plan which had proved to be thoroughly reliable in its practical operation at the Westinghouse plant at Portland, Oregon. It was however decided, in order to be able to change the initial pressure on the line in case of accident to any of the transformers, to connect the primary coils of the raising transformers in multiple to the dynamo, put the line coils all in series with the line, and with a similar set of coils in the lowering transformers, and connect the other coils of the latter in multiple to the distributing circuits.

The next question was what size of transformers should be used. Many small transformers meant less cost per unit for repairs, greater facility of handling, and greater flexibility in case it were desired to change the voltage on the line. Their use, however, also meant greater first cost, more complication, and somewhat lower efficiency, but these points were outweighed by the former, and a transformer unit of 6 K. W. was chosen. Each transformer is contained in a cast-iron box provided with vertical outside ribs, which serve to stiffen it, and also to cool the oil with which the box is filled, and which entirely covers the transformer. The box is covered by a cast-iron lid, which has conducting and radiating ribs both outside and in, the inner ones dipping into the oil at its hottest part and helping to cool it. The oil when heated rises through open spaces around the coils and spreads out in all directions, guided by the ribs on the lids, and sinks slowly down between the core and the sides of the box, thus having ample opportunity to become cooled. Each box is provided with a pet-cock at the bottom, by which to draw off the bottom layer of oil, should it become too thick by evaporation. It

also has an oil-gauge to show whether the tops of the coils are completely covered without having to raise the lid. The boxes are supported upon a substantial timber frame, upon the top of which two iron bands serve incidentally to protect the wood, but chiefly to metallically connect the boxes to each other and to the earth, in order to dissipate the static charge received by the boxes, which is very unpleasant. The core of the transformer is connected to the box by a copper strip fastened around a block of wood upon which the core rests in the box. To provide against the danger which would result from accidental connection between the primary and secondary coils, an insulated sheet of copper is placed between the latter and close to the dynamo-coil, and is connected to the core by a tongue which is stuck between the plates.

The line-coil, of No. 7 B. & S. gauge wire, is inside the dynamo-coil, and is kept everywhere at a distance of one-half inch from the latter, the ground plate, and the core, by walnut blocks boiled in paraffin, between which ample openings are left for circulation of the oil. The ratio of transformation is 1000 to 450, so that in a bank of twenty transformers the dynamo-pressure required for 10,000 volts on open circuit is 1110 volts, and on full load about 3 per cent. more than this, or 1140 volts. The space between the 1000-volt coil and the core is one-eighth of an inch. The terminals of the line-coils are brought up through the oil in mica-fibre tubes passing through heavy glass bushings held in paraffined wooden blocks which are attached to the sides of the boxes. The 1,000-volt terminals are similarly supported, but without glass bushings. The transformers are all connected in multiple to the dynamo-circuit, which is supported directly above them on a light pine framework which also supports the fuse-blocks. The latter are single-pole, and the fuse passes through a hole in a marble block, the object of so confining the arc being to blow it out by its own force. Only one fuse is used on each transformer. The secondary or line coils are all connected in series by U-shaped insulated wire connections which may be readily detached when making periodical tests for insulation of terminals, and which are entirely independent of the frame-work supporting the dynamo circuit. Accidental contact with the exposed connectors is prevented by the framework above mentioned, and there is an inflexible rule that the high tension side of the transformers shall not be touched under any circumstances whatever while the dynamo is running.

Clark's insulation is used on all wires connected to the transformers and to the dynamo, and the terminal wires of the full bank, which must often be disconnected for testing, are further insulated by heavy glass tubes at points where they might come in contact with other wires. All other transformer-wires are supported upon double-petticoat glass insulators, and all dynamo-wires upon porcelain knobs.

Switchboard.

The switchboard is of narrow redwood boards, tongued, grooved and beaded, nailed on a framework of yellow pine, the latter supported on porcelain insulators to keep it dry. The switchboard outfit for one generator and one exciter consists of two 120 amp. fuse blocks, an A. C. field rheostat with a 25 amp. D. P. field switch with fuses, an exciter rheostat, one 150 amp. ammeter and a 200 amp. D. P. jaw-switch. From this switch the current passes to two 4-dynamo, marble switch-panels which are connected in multiple to the dynamo, and are each provided with two pairs of contact plugs. By means of these panels and of two 200 amp. dynamo-changing switches below them, any feeder can be operated from any dynamo which is connected to the switch-panels. Between each panel and its switch is a pair of 65-ampere Wurts shunt-wire fuse-blocks, each provided with an extra fuse and shunt which can be connected by inserting a plug, should it be desired to double the fuses during the run on account of overload or of weakness in the fuse. The remaining instruments on each feeder are a voltmeter, a No. 1 switchboard-converter and a 150 amp. type "E" compensator. When both feeders were run from one alternator, one voltmeter was connected to the generator and the other to the feeder, and in this way the amount of compensation could be watched.

The oil-transformers were tested before shipment with 20,000 volts between the line-coil and the core, and were then taken out of the oil and boxed. In order to expel any moisture which might have been absorbed by the insulation of the coils or have condensed on the cores during their long journey, the transformers were connected in two banks of ten each, the line-coils of each set being connected in series to the generator, which was run at a reduced speed, and the secondary coils each short-circuited on itself. The coils were thus gradually heated to a point somewhat above the boiling point of water, which at that elevation was

about 201 deg. F. They were kept at this temperature for a short time and then paraffin oil of a special grade ("Diamond") was poured slowly into the boxes at the edges so that the coils would begin to absorb oil at their lower ends, and thus drive upward the air and volatile gases occluded by the insulation. The transformers were then again brought to their former temperature, which caused expansion and partial expulsion of the air remaining in the insulation. Some of the air would however collect under the insulation at the top of the coils, and had to be freed by mechanical agitation, produced by stirring the folds of insulation or by pounding on the boxes. The heat caused volatization of some of the lighter elements of the oil, these coming to the surface as bubbles, just as the air did at first, and the agitation was kept up at intervals until bubbles from this cause also were entirely eliminated.

The 20 transformers were then connected as they would be when in regular use, and the two terminals of the line-coils, which were to give 10,000 volts, were connected in series with one hundred 100-volt lamps, which were then brought to full candle power, showing that the transformers were all in good condition. A similar test was then made at Pomona at the end of the 14-mile transmission line running to that place, after which the transformers there were prepared for work in the same way as at the power-house, except that the grouping and initial voltage were changed.

Lines.

There are two transmission lines, one 13¾ miles long, which supplies Pomona, and another 28¾ miles long, which supplies San Bernardino. (See Fig. 4.) Each line consists of two No. 7 B. & S. gauge, hard-drawn copper wires. The joints in the wire are made with McIntire connectors. To further improve the joint, the ends of the wires were bent back side by side and soldered together. After the Pomona line was completed and the first ten miles of the San Bernardino line was put up, the supply of connectors ran out, and the regular telegraph joint was substituted. The conductivity was assured by soldering as before.

The wires are supported upon large double-petticoat flint-glass insulators designed for this plant. These insulators are of perfectly clear flint-glass, which gives a better surface-insulation than is attainable with any other kind of glass.

It was at first proposed to use oil insulators. The reason they were not used was because the glass companies which had undertaken to furnish them found on trial that they could not make them without considerable experimenting, which would have delayed the installation of the plant. This was no doubt fortunate, as the country through which the line passes is subjected to hot, dry winds which not only blow dust onto the insulators, but also inside them, and during the day the sun beats on the insulators until they become so hot that they nearly blister one's hands. If oil were used under these conditions it would soon evaporate and thicken, and become filled with dust. It would therefore seem undesirable to have used oil insulators in this case, or to

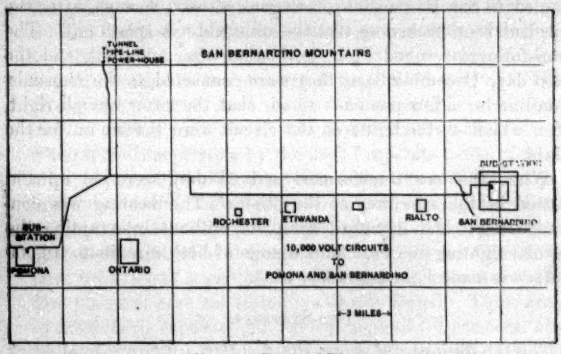

FIG. 4.—Route of Lines.

use them in any other until an increased voltage makes them necessary, and the transmission of greater amounts of energy over the circuits justifies the additional expense necessary to keep the insulators in good condition.

The two circuits are carried on the same pole line for 7½ miles. (See Fig. 4.) The inside pair of pins was used for the circuit to Pomona and the outside pair for that to San Bernardino, until after the acceptance of the plant, but in anticipation of the installation of another generator the Pomona circuit was changed to the right-hand pair of pins, and the San Bernardino circuit to the left-hand pair, to avoid the fluctuation in lights which would result from inductive interference between two independent circuits.

Commercial lighting in Pomona was begun November 28th, 1892, and a telegraphic order was at once sent for another set of reducing transformers, to be used at San Bernardino, where the local circuits were already nearly completed. It was a condition of the franchise for the latter place that lighting should be begun before January 1st, and work was pushed rapidly on the transmission line, over 28 miles long, until it was finished. The order for transformers had, however, been given too late for them to be delivered in time, and it was decided to reduce the pressure at Pomona to 5,000 volts and to take to San Bernardino the half of the Pomona bank thus made available. In order to avoid the re-heating which would have been required had the transformers been dismounted for shipment, the latter were hauled to San Bernardino on wagons without springs, after the lids had been packed so that the oil could not splash out. The transformers reached their destination after midnight, and the next day, December 31st, they were connected to the transmission line for a few moments to see that the latter was all right, after which all the lights on the circuit were thrown on for the night.

When the new transformers arrived they were set up and heated in the same way as the others. The heating was continued night and day until complete, without interrupting the regular lighting service. The change of both circuits to 10,000 volts was made February 16th, 1893.

Sub-Stations.

The sub-stations at Pomona and San Bernardino are small brick buildings, one story high, with flat tin roofs and numerous windows. The Pomona building contains two rooms connected by a door near the switchboard. The front room is used as the office of the company, and the other as a transformer room. The 10,000-volt circuit enters over the door, and is connected directly to the bank of lowering transformers, no switches or other appliances being used on the high tension lines either there or at San Bernardino. The switchboard appliances are a Stillwell regulator, two 100-amp. marble fuse-blocks with double plugs and fuses; a 100-amp. jaw-switch, 150-amp. ammeter, compensating voltmeter, compensator and converter.

The San Bernardino sub-station is longer than that at Pomona, and is not divided by a wall. The transformers are placed in a

row along a side wall, and along part of the end wall next the switchboard. The transformers near the switchboard heat the most. This is probably due to the slight drop in wiring between them and the more distant converters. During the first year of operation a little new oil was put into the converters about every four months to make up for that evaporated, but none of the old oil was drawn off. The switchboard apparatus is like that at Pomona.

The Stillwell regulator has long been recognized as a valuable adjunct to the central station operating a number of feeders of different lengths from a single dynamo. Its utility is still greater in a system of long-distance transmission in which the transmission circuits are supplied from one dynamo, as was the case in this plant during its first year of operation, since it is not practicable to install such a system so as to operate with small line-loss, and therefore means must be provided to compensate for the large differences in the pressure at the ends of the lines. The use of regulators at the power-house was impossible when but one bank of raising transformers was used for the two circuits. Even when it became possible by the use of separate banks of transformers, it was still undesirable because the attendant at the power-house would often have had to work both the regulators at once to properly compensate for changes in load, and his attention would have been required by the regulators at exactly the time he should have been free to attend to the generators. A regulator was therefore placed at each sub-station, as already stated. These are each of 2000 lights capacity and have a range of 10 per cent. up, and 10 per cent. down. This variation of 10 per cent. (100 volts) is divided into 14 equal parts, so that each step corresponds to 7.1 volts. The diagram (Fig. 5) was taken one Sunday, while using only 5000 volts, and shows the number of changes required during the evening at each station. The line marked "off" is the base line, and the divisions above and below correspond to the steps on the dial and show to what an extent the regulators were used to increase and decrease the pressure. This diagram shows how impossible it would be to furnish lights without using regulators, even on Sunday when the load is much smaller than on other days. It also shows that on that day the pressure at Pomona was being mostly reduced while that at San Bernardino at times (as at the point marked "very bad light") could not be sufficiently increased. This indicates that the pressure of the lowering trans-

formers at one of the sub-stations should be changed so as to make the pressures at both more nearly equal, and thus increase the effective range of the regulators. In the present plant this is done by changing the number of transformers.

The distribution from both sub-stations is effected in the usual manner at 1000 volts for incandescent lighting, the only point of interest being that a considerable number of Helios arc lamps are successfully used on the incandescent circuits.

Observations.

While in use, the transformers in the sub-stations give forth a continuous hum which depends for its tone on the number of alternations. This is an excellent indicator for the attendant, whose attention is instantly called to any change in the running conditions of the plant by the resulting change of tone. Its indications not only mark changes which are taking place and which can be detected on the voltmeter, but also give notice of coming changes before there is any other indication of them. It is thus possible to foretell a coming drop in voltage in time to use the regulator and thus keep the voltmeter needle perfectly still, though the voltmeter is a very sensitive instrument, and the regulator is often moved four or five notches. The hum often changes, however, without any corresponding movement of the voltmeter, but the sound is then somewhat different. At rare intervals the switchboard lights will suddenly change slightly in candle-power before any change is noticeable on the voltmeter.

It is noticeable that the needle will often stand for a time perfectly still on the center, and, on a slight rise in the hum, will start gently rising, never more than three quarters of an inch, and then as the tone gradually becomes lower, slowly fall back to the center and stop without passing it. At other times the variation in hum is more sudden and the needle will rise and oscillate above the center. Again, the needle will oscillate equally about the center during a regular rise and fall of hum, its movement being apparently due to one impulse and not seeming to be modified by subsequent variations. There is no apparent change in candle-power of the lamps during the voltmeter changes noted. These notes were made while the plant was running at only 5,000 volts, but they were later confirmed when using 10,000 volts. During dry weather there is considerable intermittent oscillation of the voltmeter-needle without there

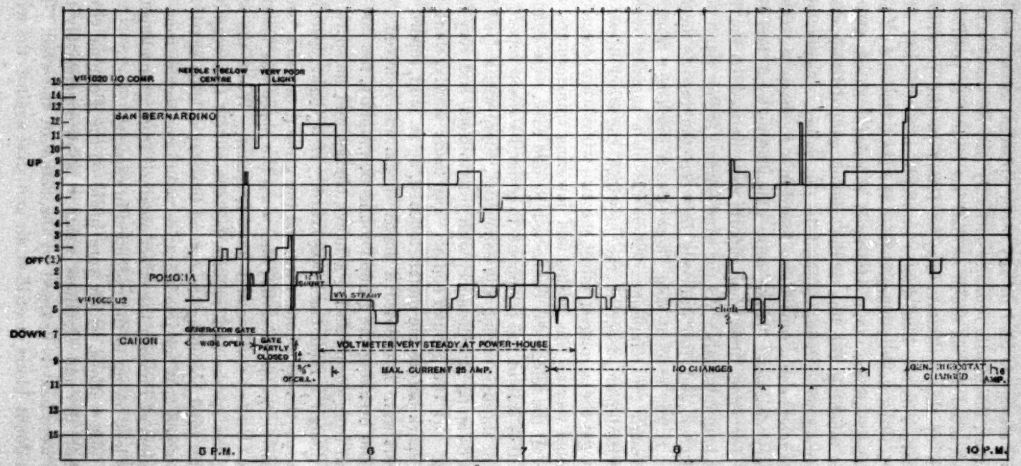

FIG. 5.—Diagrams Showing Use of Stillwell Regulators at Pomona and San Bernardino, with Notes of Simultaneous Conditions at Cañon.

being any change in load or any other apparent cause, while in wet weather, the needle remains perfectly still for many minutes at a time, often for as much as half an hour. A possible explanation of this oscillation may be found in the presence of static charges on the line, due to atmospheric electricity. That the line is often heavily charged from the air, is shown by a number of observations. One afternoon a painful shock was obtained on touching the line at the canyon end, drifting clouds and a strong wind being noticed in the valley. Again, while using the telephone a report was heard in it so sharp as to cause momentary deafness. Later, after a moderate wind had been blowing for some time, loud reports were noticed on the telephone at long intervals. As the wind became higher the reports came oftener, and the intervals between the reports became shorter. It was evident that there was a discharge from the lines through the telephone (which was on a metallic circuit) and that it depended on the rate at which the wind blew. In order to get the strongest effect the two wires were connected in the usual way to the raising and lowering transformers, and one side of the telephone connected to one wire. On connecting the other side of the telephone to ground a sharp report was heard, and on maintaining the connection there was a sound as of steam escaping at a distance, with intermittent and very faint crackling. If the ground contact was made slowly, there was a bright spark before the metals touched, and a loud report. If the fingers were interposed a smart shock was received. By making and breaking the ground connection rapidly, the line was prevented from accumulating a heavy charge, and no spark was visible, though a faint crack was heard. If a slight space was left between the telephone wire and the ground, a spark occurred at fairly regular intervals, and when the space was lessened the sparks became smaller and more frequent. When the wind lessened, the sparks and reports become almost imperceptible, but on the wind becoming strong and blustery a large spark was again obtained. When one line wire was disconnected from the transformers at Pomona the effect obtained from grounding that wire was less, owing to the reduction in capacity.

These observations, which were made on the Pomona circuit during hot, dry and cloudless weather, show conclusively that the lines were heavily charged by the action of the wind. The wind no doubt blows electrified air and dust against the wires,

the latter thereby accumulating a static charge with a rapidity which we have seen depended on the speed of the wind.

Some curious conditions met with in the operation of the plant are shown in the ampere curves in Fig. 6, which were taken during very wet weather. Taking the maximum load measurements at 7 P. M. for March 14th and 8th, we note that the total apparent energy delivered by the sub-stations is 73 per cent. and 75 per cent., respectively, of that delivered by the generator, while for a smaller load at 9 P. M. the respective percentages decrease to 47.6 per cent. and 48.6 per cent. in spite of the fact that the apparent energy delivered by the generator is in the latter case only half as great as in the former. These results are due to changes in the angle of lag caused by changing the load.

In the Cañon curve of March 8th, the load at 9.30 P. M. is seen to have increased considerably, although the sub-station loads were decreasing. This increase was due to the fact that the rain which had previously ceased to fall at Pomona, began again.

Tests.

The electrical resistance of the Pomona circuit is 74.9 ohms and that of San Bernardino 156.4 ohms at about 90 degrees F.

The insulation resistance of the circuits varies from far beyond the limits of an 11-megohm bridge in dry, hot summer weather, to as low as 0.65 megohm during light rain. The latter value is that obtained with the two San Bernardino wires in series, and represents an insulation-resistance per mile of over 37 megohms. On a clear, sunny day the insulation-resistances of one Pomona wire and of one San Bernardino wire were respectively 11 megohms and 5½ megohms, which are in the exact relation which would be expected.

The lines cannot be tested for grounds or for continuity with a magneto bell, as their capacity is such that the bell will ring loudly when the wire is perfectly insulated and the circuit open. This capacity also prevents the use of the ordinary converter test for line leakage, as the lamp on the secondary will burn as though there were a ground even when the line is perfectly clear. By adding lamps, however, the light may be cut down until the last lamp added extinguishes them all. This would not occur if the light of the first lamp was due to a difference of potential on the primary caused by a ground, as then the added lamps would be-

come as bright as the first. The primary current is thus seen to be limited, and to be due to the capacity of the line. If the proper number of lamps has been added, to just secure darkness when the line is known to be free from grounds, the converter

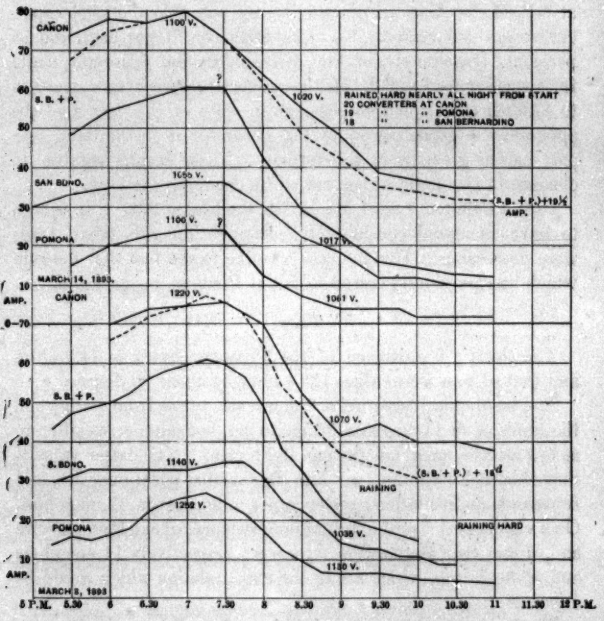

FIG. 6.—Ampere Curves. Showing Excess of Cañon Load over the sum of Pomona and San Bernardino Loads, and also Decrease in Difference between Cañon Load and this Sum as the Cañon Load Increases.

Notes on March 8th. Raining in afternoon and nearly all night at Pomona. Snowing throughout canyon and a mile or so outside of mouth of canyon. 8 inches of snow at power-house, covering insulators and cross-arms completely. 1 inch of snow on wires. Snow damp and clinging. No wind. 20 converters at Cañon, 19 at Pomona and at San Bernardino.

may be used to show grounds on that line, since the presence of a ground will cause all the lamps to brighten. The line test should only be made after ascertaining with one lamp that the generator is not grounded, as otherwise the leakage cur-

rent for the greater number of lamps might burn the insulation of the generator. A very good example of Prof. Fleming's "condenser effect" was met with in the Summer of 1893, while the engineer was trying this converter test for measuring line leakage. The primary of a 1000—100-volt converter was connected between the ground and one terminal of the generator, the other terminal of the latter being connected to one wire of the Pomona circuit. The resulting secondary pressure

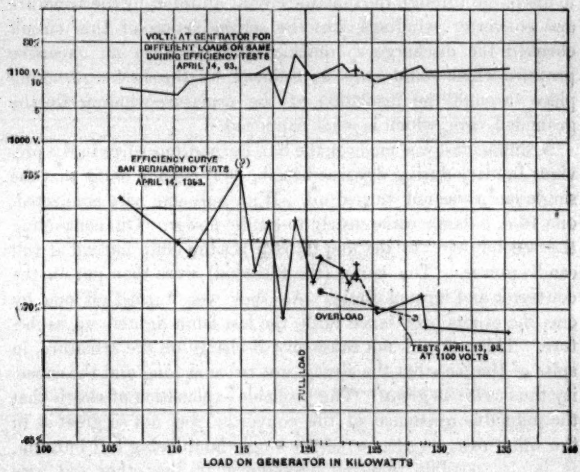

FIG. 7.

was 30 volts, which made one lamp burn dimly. When ten lamps were turned on, the pressure dropped to 14 volts. When all lamps were turned off the pressure became ten times as great, or 140 volts. One generator brush was then raised, and the second wire of the circuit was connected to the first. On completing the circuit again there was a sudden flash on the armature, followed by a crackling noise and a brush discharge which lasted until the circuit was broken. The Pomona wires were then disconnected from the dynamo terminal, which was left free. With this arrangement faint sparks and a glow were noticed, as

though the armature winding were grounded on the core, but a Wheatstone bridge test showed an insulation resistance of over 10 megohms. Since then the machine has been used regularly and has not broken down, so it is evident the spark must have resulted from a sudden increase of the potential of the armature winding above that of its core, which latter was permanently connected to earth.

This sudden increase may be explained as follows. On closing the circuit the condenser formed by the line and the earth began to discharge through the metallic circuit afforded by the armature and converter windings, but the self-induction of this circuit checked the discharge so quickly as to produce an excessive pressure which could only be relieved by the discharge taking place through the insulation of the armature-winding to the grounded core, which is what happened.

A similar test was made on the San Bernardino wires in the previous January during dry weather, the only change being that the single lamp was not turned off. With only one wire connected, one 16 C. P. lamp came nearly to candle-power. On connecting the second wire to the first (at San B.) the lamp burned at full candle-power. Ten lamps (the full load) were then put on the converter and burned dimly. As they were turned off one by one, the others brightened until the last lamp lighted up as before. This test did not cause any discharge on the armature, in spite of the fact that the circuit was twice as long and the capacity thus twice as great. The probable explanation of this is that the inductive resistance of the converter was not so great as in the other case, on account of the single lamp being left burning. It is also possible that the breakdown in the other test was assisted by the presence of copper dust on the winding.

A comparison between the ammeters used at Pomona and San Bernardino showed that for readings above 67½ amperes the San Bernardino instrument read higher than the other. As there was no reason for considering one instrument more accurate than the other, and no way of telling which was right, the San Bernardino readings taken during the test were reduced to the average of simultaneous readings on the two instruments.

A short test of the Pomona circuit was made on April 11th, the results of which are given in Table I.

A preliminary efficiency test on the San Bernardino circuit was made April 13th, 1893, with the results shown in curve in Fig.

7. In this, as in all the other tests, a variable load was obtained by the use of a water resistance.

An efficiency test of the San Bernardino circuit lasting five hours, during which the generator was kept at full load or overload, was made April 14th, 1893. The voltage at San Bernardino during the tests was measured with a Weston portable voltmeter. Readings were taken every fifteen minutes, and the efficiencies and the corresponding voltages for different loads are

TABLE I.

EFFICIENCY TESTS. POMONA CIRCUIT.

April 11th, 1893.

Cañon (90 Converters).			Pomona (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
120	1100	132	105.85	919	97.28	73.7
118.5	1100	130.35	105.85	945	100.01	76.73
119.5	1100	131.45	107.4	929	99.78	75.9

TABLE II.

42½ MILE TRANSMISSION TEST. CIRCUIT TO SAN BERNARDINO, BY WAY OF POMONA, 85 MILES.

May 2nd, 1893.

Cañon (20 Converters).			San Bernardino (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
95	1120	106.4	80.75	847	68.4	64.28
96	1130	108.5	78.8	865	68.16	62.82
100	1200	120.0	81.7	893	72.96	60.8

plotted in Fig. 7. The most prominent feature of this efficiency curve is its irregularity. This is, however, satisfactorily explained by referring to the curve of generator voltage, on which it is seen that the high efficiencies correspond to high voltages, and *vice-versa*.

It will be noted that the apparent efficiencies shown by the preliminary test at San Bernardino agree very closely with the results of the long efficiency test there. On calculating the apparent efficiencies for different loads from data obtained by lab-

oratory tests, and comparing them with the measured apparent efficiencies, it is found that they agree within three or four per cent. This very close agreement is exceedingly gratifying, particularly when we consider that the tests of the plant were made with ordinary commercial instruments, and that the laboratory tests were made about a year before the commercial tests.

An interesting and unique test was made May 2d, 1893, by connecting the Pomona line wires in series with the San Bernardino circuit, and transmitting about 100 H. P. to San Bernardino by way of Pomona. The length of the circuit was 85 miles, and the distance of transmission 42½ miles. This is the greatest distance yet covered by any transmission since the Frankfort experiments. The measurements are given in Table II. The apparent efficiencies are much lower than those indicated by calculations, as in the latter no account was taken of the capacity and inductance of the circuit. The voltage of the generator as measured is about 5 per cent. above that calculated, and the amperes measured, notably exceed the amperes calculated. These results are attributable to the introduction of the Pomona loop, which added both capacity and inductance.

In order to reduce the cost of operation, the San Antonio Company first dispensed with the sub-station attendant at Pomona after 11 P.M. This they did sometime before the acceptance of the plant, after assuming the responsibility for any damage which might result. No trouble occurred and, after the acceptance (May 6th, 1893,) the same plan was put in operation at San Bernardino. After working in this way for several months, the Pomona station was started in the afternoon and then locked up until the next morning. This arrangement was made possible by running the generator so that the pressure would be right at Pomona, the pressure at San Bernandino being kept right by the attendant with the Stillwell regulator.

In January, 1894, another 120 K.W. generator was installed with an equal capacity of oil transformers, and the Pomona and San Bernardino circuits are now each operated from separate generators with separate banks of transformers at 10,000 volts. Since this change the San Bernardino attendant has also been dispensed with, and the book-keeper starts up in the afternoon and then locks up the station for the night, as at Pomona. The voltage of the lamps on each circuit is regulated by the engineer at the power-house, the generator pressure necessary at different

loads to keep the lamps at the proper brilliancy being automatically indicated by the compensating voltmeter on each circuit. Thus after the plant is started the engineer has sole charge.

The following associate members were elected at the meeting of Council held at Niagara Falls, June 27th, 1895.

DANIELSON, ERNST,	Consulting Electrician, 16 Scheele Gatan, Stockholm, Sweden.	Elihu Thomson. E. W. Rice, Jr. H. M. Hobart.
GHERARDI, BANCROFT, JR.,	Assistant in the Engineering Dep't Metropolitan Tel. & Tel. Co.; residence, 6 East 34th St., N. Y. City.	W. L. Bliss. Sam'l Sheldon. A. L. Riker.
HESSENBRUCH, GEO. S.,	Assistant Electrical Engineer Accumulatoren Fabrik, Hague, Germany; 3 Head Place, Boston, Mass.	B. C. Paddock, Jr. F. Wm. Erickson. R. W. Pope.
HORNSBY, HARRY H.,	Electrical Inspector, City Hall; residence, 1801 Barry Ave., Chicago, Ill.	C. C. Haskins. B. J. Arnold. L. K. Comstock.
HUGUET, CHAS. K.,	Instructor in Electrical Engineering, Tulane University; residence, 1216 Carondelet St., New Orleans, La.	Brown Ayres. A. L. McRae. A. F. McKissick.
JEHL, FRANCIS,	Representative, F. Hardtmuth & Co., 60 Liberty St., N. Y. City.	Wm. J. Hammer. R. W. Pope. Francis R. Upton.
MERRILL, EDWARD B.,	Principal and Instructor in Electricity, etc., at the Toronto Technical School; residence, 38 Cecil St., Toronto, Ont.	T. R. Rosebrugh. John Langton. W. M. Rutherford.
ORMSBEE, ALEX. F.,	Electrical Engineer; residence, 183 Joralemon St., Brooklyn, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
PEIRCE, ARTHUR W. K.,	Instructor in Electrical Engineering, The Colliery Engineer Co., Scranton, Pa.	J. Hally Craig. Geo. Cutter. Wm. H. Donner.
PRICE, EDGAR F.,	Electrician, Newark & South Orange Railway Co.; residence, 16 Rector St., Newark, N. J.	Philip A. Lange. L. A. Osborne. H. M. Wharton.
SAWYER, FRED. W.,	Student, Worcester Polytechnic Institute; residence, 42 Harvard St., Worcester, Mass.	A. S. Kimball. R. W. Pope. Edw. Caldwell.
TORCHIO, PHILIPPO,	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane St., N. Y. City.	Wm. J. Hammer. E. A. Leslie. J. W. Lieb, Jr.
YOUNG, CHARLES I.,	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.	A. J. Wurts. Chas. F. Scott. L. B. Stillwell.

Total, 13.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 27th, 1895. President Duncan in the Chair.

ALTERNATING CURRENT CURVES.

BY CHAS. E. EMERY, PH. D.

§ 1. The sine curve used to represent the variations in magnetization, electromotive force and current, has the advantage that the same curve is applicable for each of the three phenomena and that the changes in sign and direction are repeated periodically, so that differences in the phase relations of the different curves may be conveniently represented by the angles between several radii of a generating circle. The resulting trigonometrical functions have enabled elaborate general investigations to be successfully carried on, and satisfactory solutions have been obtained, applicable strictly only to the conditions assumed, but which indicate the nature of the variations which would result under different conditions.

§ 2. With sine curves the watts may be obtained from the current and electromotive force and the difference in phase between the same, but for other than sine curves this method is strictly applicable only when the current and E. M. F. are in phase, though very valuable practical results have been obtained by special methods involving "equivalent sine curves" and a modified or "equivalent angle of lag." It is therefore desirable to develop a general system for formulating and integrating the values of the "instantaneous watts" applicable to curves of different shapes which will include an approximate sine curve as a special case. Such a system should avoid the necessity of using "equivalent" values and enable the distortions of alternating current curves to be explained directly, by formulating the conditions which produce the same instead of considering arbitrary "harmonics."

§ 3 The following is a statement of the principal require-

ments of curves which will fairly represent observed phenomena:

I. The curve used should at least so resemble the experimental curve that, when not superimposed, it will appear identical to the eye on the small scale used for illustration.

II. It is desirable that the same function represent curves greatly differing in appearance, such for instance as those approximating rectangular or triangular shapes or the sine form.

III. The function should be of a kind that the resulting equations, showing instantaneous values of electromotive force and current, can readily be multiplied together to show instantaneous watts.

IV. The original and all resulting equations should be readily integrated by *inspection* so that the total watts or other desired quantities can be obtained directly from such equations.

V. The function and resulting equations should be of such kind that further conditions may be imposed upon conditions already embodied, and thereby the influence of hysteresis, and other phenomena less striking but more important, be expressed in the form of equations and resulting curves, and the influence of one condition upon another studied mathematically in connection with observed distortions of experimental curves, without changing the general features of the equations so as to prevent integration by inspection as previously stated. The object of such investigations should be to bring directcurrent formulæ and alternating current formulæ for momentary values into the same shape, so that the various conceptions will be simplified and the modifications appear to be due only to the new conditions imposed.

§ 4. The writer has developed and applied a simple, well known algebraic function which appears to satisfy the first four of the five general requirements above stated, and has made progress with the very many important problems involved in the fifth requirement, but since delay in obtaining complete results is inevitable, it has been thought desirable to present in detail the distinctive features of the method, so far as satisfactorily developed in order that it may become familiar to others working in the same line, and perhaps have the effect, by the introduction of a number of workers, to hasten the consummation of the desired end.

§ 5. The details of the method will be much more readily comprehended by a preliminary elementary presentation along similar lines of matters already understood by those familiar with the subject.

§ 6. The electromotive force in a conductor under the influence of alternating magnetism is generally stated to be at any instant, proportioned to the rate of change in magnetic induction, which is equivalent to the rate of change of magnetism or in the number of magnetic lines of flux included at the moment in the circuit.

§ 7. In Fig. 1, *e* represents a curve of alternating E. M. F. and *m* the corresponding curve of alternating magnetism. A complete period is represented by four divisions, those included between ordinates *a a*, for instance, laid off on the axis of abscissa X X. Measurements to the right from an origin to be fixed by the conditions are herein to be considered plus, and those to the left, minus, as customary in geometrical delineation; the variations being as if an *ordinate to mark the time were moved clockwise across the curves* proportionally to the time. The ordinates of the curve *e* represent the mometary values of the variable E. M. F., and the number of lines flowing momentarily in the magnetic circuit is represented by the ordinates of the curve of magnetization *m*.

§ 8. It is well known that the rate of change of a variable ordinate of a curve is represented by the tangent to such curve, and the equation of the tangent is the differential of the equation of the original curve, so, since the curve *e* represents the rate of change of the ordinates of the curve *m*, the equation of the curve *e* is the differential equation of the equation of curve *m* and the ordinates of curve *e* represent proportionally the values of the tangents of curve *m*. When the value of the magnetization *m* is zero, as at *a*, the tangent to the curve is a maximum and the ordinate of the curve *e* of E. M. F. is also a maximum. Again, when the magnetization is a maximum, as at ordinate *b*, the tangent to the curve is zero and the E. M. F. shown by curve *e* is also zero.

§ 9. The curves *m* and *e*, as drawn, are based on sine functions and are, therefore, similar and equal, but located one-quarter phase apart along the time axis. If any other than a sine function be employed, the two curves are dissimilar, but the equation of *e* will still be in the differential equation of the equa-

tion of curve m, and the two curves be at a quarter phase the same as before.

§ 10. Sine curves for rectangular coordinates, Fig. 1, may be considered generated by moving a time ordinate uniformly from left to right and revolving clockwise at the same time a generating radius r, Fig. 1a, uniformly about a center O and plotting the ordinates of the two curves in Fig. 1 from the sines and cosines of the arcs through which the radius r is moved in Fig. 1a. In these figures, as drawn, the radius r, Fig. 1a, should be moved through 90° in the same time that the imaginary time ordinate is moved one division in Fig. 1. The method of revolving two generating radii fixed 90° apart will evidently give the same result as by using the sine and cosine, but the latter is required in the mathematical treatment of the subject.

§ 11. If for sine functions θ = the angle through which the generating radius is moved uniformly, or proportionally to the

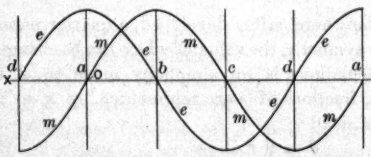

FIG. 1.

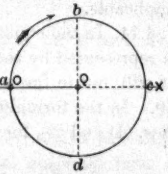

FIG. 1 a.

time, the fundamental equation applies to the value of the magnetization and we have

$$y = \sin x = m = \sin \theta. \tag{1}$$

$$\frac{d\,y}{d\,x} = \frac{d \sin \theta}{d\,\theta} = e = \cos\ \theta. \tag{2}$$

§ 12. The equations show, that at any particular moment, the ordinate of a sine curve of magnetization simply equals the sine of the angle through which the generating radius r has been moved, and that the corresponding ordinate of the curve of E. M. F. which equals the tangent of the curve m, plotted in a system of rectangular coordinates, Fig. 1, is equal to the cosine of the angle through which the generating radius has been moved, thereby confirming the previous statement.

§ 13. Sine curves plotted from Eqs. (1) and (2), or as described, reverse at regular intervals and develop equivalent branches of what may be termed a sinusoidal curve. If it be at-

tempted to use any other than a sine function as a basis of a representative curve, such curve can only be applicable between limits. Evidently, however, the positive and negative branches of any alternating curve are, if symmetrical, in one sense duplicates of each other and merely reversed and changed in position. A curve based on any function may be satisfactorily studied between the limits of tangent zero and tangent maximum which corresponds to a quarter period for alternating current curves, and an equation of such curve will give positive and negative branches which jointly extend through half a period. Evidently such branches can graphically be reversed and combined so as to form a curve reversing in direction regularly like a sinusoidal curve, and it is not necessary for accuracy to express the whole operation mathematically, as all the elements of the combined curve required for our purpose are included in one of the parts developed from the formula between the limits for which it is applicable.

§ 14. In the equations hereinafter developed, a quarter period is represented by the symbol s, the value of which can be changed at will, but in the calculations, is for simplicity made equal to 10. In the formulæ, fractions of s are represented by x, so in Eqs. (1) and (2), for $s = 10$.

$$\theta = 9\,x. \tag{3}$$

§ 15. For convenience, a maximum diagram height of 10 has also been selected and corrections are to be made for actual values by numerical coefficients. The several curve values are distinguished as "diagram magnetization," "diagram E. M. F." and "diagram current," and provision made to reduce these quantities to actual magnetization, E. M. F., and current, in practical units, without intermediate expression in "absolute" measurements, which are evidently one-tenth of the diagram units.

§ 16. With the sine function it is convenient to consider a base of $2\,\pi$ or one complete period; a to a, Fig. 1, for instance, For the equations herein developed applicable to various curves of very different shapes, a base of one-quarter period is employed, which is extended to one-half period by the reversals due to negative values. It should be borne in mind at the outset that the base has nothing to do with the results. In all representative curves the value of the ordinates is stated in terms of the base and apparently of the time which the base represents, but actually the time is not considered in this way, as the E. M. F. depends upon the

"frequency" or number of complete cycles per unit of time which is always introduced as an arithmetical factor independent of the function. It is, therefore, necessary to divide out the base, whatever system is adopted, before multiplying by the factor of correction. In some alternating current formulæ this precaution does not appear to have been taken.

§ 17. The general equations are based on the simple algebraic function,[1]

$$y = A_1 x^n. \qquad (4)$$

§ 18. In this and subsequent equations

y = in general the variable ordinate of the curve considered.

x = the variable abscissa.

x_1 = the length of base between limits of integration.

s = one-quarter the length a, a, Fig. 1, or a quarter period along a time axis, but not to be considered as time, for reasons explained in § 16. Usually s is made equal to 10.

u = an arbitrary partial exponent, constant for a particular series of solutions.

v = the same for equations of series I.

A_1 = a general constant.

$(f\,A)$, read function of A, = a factor introduced to reduce ordinates of the curve m to actual magnetic lines of flux.

A = a constant representing the approximate value of $(f\,A)$ for the particular conditions considered, the modification being necessary to obtain a solution of the equation.

A_2 = a constant of reduction providing for the number of turns, arithmetical constants, etc., necessary to reduce ordinates of curve e to actual values of E. M. F. in practical units.

A_3 = a constant of reduction to provide for resistance, inductance, etc., in reducing E. M. F. to current.

1. Some of the remarkable properties of this function have already been pointed out by the author in a paper on "Rational and Empirical Formulæ showing the Relation between the Magnetomotive-Force (H) and the Resulting Magnetization (B)," TRANS. AM. INST. EL. ENGRS.; June, 1892, in which was given for consideration some reasons why magnetic lines should be considered as a translatory movement of an ether. (Such a theory is simply suggestive. It requires not only that the transverse current of Maxwell be either identified with or act as the cause of the magnetic lines, which may in time be accepted, but it also requires that the experiments of Herz be referred to causes other than those stated, for which there is as yet no reason except the possible errors of indirect methods).

$B = AA_2$

$D = AA^2 A_3$

m = diagram magnetization or the length of the ordinates of a diagram or curve representing momentary magnetization.

$M = \frac{Am}{s}$ = actual magnetization or total nmber of magnetic lines momentarily flowing in the circuit considered.

e = diagram E. M. F. or lengths of ordinates on diagram representing E. M. F.

$E = \frac{B\,e}{s}$ = actual E. M. F. above zero in volts.

c = diagram current or the length of the ordinates of a diagram representing current.

$C = \frac{D\,c}{s}$ = actual current in amperes.

$w = e\,c$ = momentary diagram watts or the product resulting from multiplying momentary diagram current by momentary E. M. F.

G = integral of diagram watts between limits to be mentioned.

w_1 = average diagram watts by integration.

$W = \frac{B\,D\,w_1}{s^2}$ = actual watts in practical units.

§ 19. From the function shown in Eq. (4) two series of equations are developed, viz: Series I with origin at zero of curve of E. M. F., and Series II with origin at zero of curve of magnetization. For Series I the resulting curves do not as closely resemble practical curves of magnetization and E. M. F. as those of Series II, but both are given to show the remarkable properties of the underlying function.

§ 20. For Series I, using v as the partial exponent we obtain preliminary values distinguished by sub. 1 as follows:

$$e_1 = \frac{d\,y}{d\,x} = x^v, \tag{5}$$

in which form the origin must be at zero of E. M. F. or at ordinate d, Fig 1. Integrating we have

$$m_1 = y = \frac{1}{v+1}\left(x^{v+1} + C\right) = -\frac{1}{v+1}\left(s^{v+1} - x^{v+1}\right) \tag{6}$$

The value of the constant of integration C is readily determined from the condition that when $y = o$, $x = s$.

§ 21. For Series II. we obtain preliminary values as follows:

$$e = \frac{d\,y}{d\,x} = s^u - x^u. \tag{7}$$

Integrating we have:

$$m = y = s^u\,x - \frac{x^{u+1}}{u+1}. \tag{8}$$

In Eq. (8) the constant of integration has been omitted, as the origin remains in the same place as in Eq. (7).

§ 22. It will be observed that the values of the ordinates are shown in terms of the maximum base s. In the calculations herein s is made equal to 10, though the symbol is preserved to permit a ready change of base. The maximum ordinates vary in the four equations above given, so, for convenient practical application, we divide through by the maximum ordinate of each, and multiply by s, so that the ordinates as plotted and as shown by the following equations are in terms of s or ordinarily in a scale of 10. We then have the following:

§ 23. Series I. for Final Equations of Curves with Origin at Zero of E. M. F.. From Eqs. (5) and (6).

$$e_1 = \frac{1}{s^{v-1}}\,x^v. \tag{9}$$

$$m_1 = -\frac{1}{s^v}\left(s^{v+1}\,x^{v+1}\right). \tag{10}$$

§ 24. Series II. for Final Equations of Curves with Origin at Zero of Magnetization. From Eqs. (7) and (8).

$$e = s - \frac{x^u}{s^{u-1}}. \tag{11}$$

$$m = \frac{u+1}{u\,s^u}\left(s^u\,x - \frac{x^{u+1}}{u+1}\right). \tag{12}$$

§ 25. If in the equations of Series I., $v = 0$, the curve of E. M. F. or e is, as shown in Fig. 2, a rectangle, and the curve of magnetization m a triangle, the phase relations in all cases being as described for Fig. 1.

§ 26. If in Series I., $v = 1$, the curve e, as shown in Fig. 4, becomes a triangle and the curve m an ordinary parabola. The parabola very much resembles a sine curve when one is not superimposed upon the other. See § 31.

§ 27. Referring to Fig. 3, for which in Series I, $v = 0.5$, it will be seen that as v increases from 0 to 1 the curve e becomes pointed with rounded sides like the point of an acorn, and the

curve m, though retaining the rounded top, approximates the shape of a triangle as the value of v approaches unity. For $v = 0.75$, however, m is practically a sine curve, though the corresponding curve e retains the sharp point.

§ 28. As v becomes greater than unity the curve of E. M. F. is

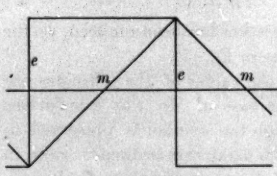

FIG. 2.—Series I, $v = o$
Series II, $u =$ Infinity.

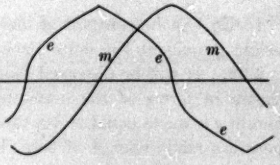

FIG. 3.—Series I, $v = 0.5$.

in cusp form, viz: has a sharp point with hollowed side, and the curve m is broadened at the top, so that the curves resemble those shown in Fig. 5.

§ 29. If in Series II, $u = 1$, as shown in Fig. 4, the curve of E. M. F. or e becomes a triangle and the curve of magnetization m a parabola, showing that the values for partial exponent u or $v =$ unity are for both series of equations identical.

§ 30. As shown in Fig. 5 for which $u = 0.5$ in Series II, for values of u between unity and zero, the curve e takes a cusp form and the curve m a rounded form.

§ 31. If in Series II $u = 2$ both curves e and m, as shown in

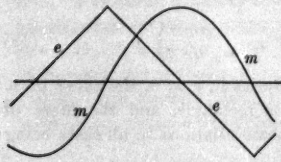

FIG. 4.—Series I, $v = 1$.
Series II, $u = 1$.

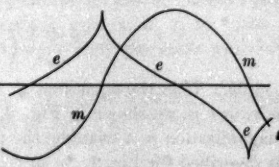

FIG. 5—Series II, $u = 0.5$.

Fig. 6, approach the sine form represented in dotted lines, the curve e being a parabola slightly greater in area than a sine curve and the curve m consequently of slightly less area than a sine curve.

§ 32. By using a fractional exponent both curves can be

brought still closer to the sine form. For $u = 1.781$ in Eq. (11) the square root of the mean square of the ordinates of the resulting curve e is 7.071 or the same as for the sine curve. The two curves being derived from different functions cannot absolutely coincide, but the differences are so slight that to find them the values must be extended to several decimal places, and, in plotting, the curves seem identical.

§ 33. If in Series II, the value of u be still more increased, the curve of magnetization m rapidly approximates the shape of a triangle and the curve e of E. M. F. approximates a rectangle, so that doubtless for $u =$ infinity, the curve would take the form shown in Fig. 2 for Series I, $u = 0$.

§ 34. The change above indicated is so rapid that for $u = 6$ in Series II, as shown in Fig. 7, the curve e has already taken the general shape of a rectangle with well-rounded corners, and the curve m the general shape of a triangle with rounded point. The curve e resembles closely the curve of electromotive force given by a dynamo from which armature reaction has been eliminated, as shown in a recent paper,[1] and the corners may be made still sharper by increasing the value of u.

§ 35. Unsymmetrical curves based also on $u = 2$ in Eqs. (11) and (12), Series II, are shown in Fig. 8. These curves are plotted with the same values of the ordinates as in Fig. 6, but the portion of the curve showing decreasing magnetism and increasing E. M. F. is plotted in a distance less than a quarter period, and the remainder of the curve in a distance greater than quarter period, so that the sum of the bases equals one-half period. These curves show that the phase relation of curves m and e may be changed simply by the shape of the curve m of magnetization. The plus and minus branches of this curve must be similar and of equal area, but the change of magnetism and of electromotive force during the increase of the latter need not be at the same rate as during the decrease.

§ 36. It will be observed that this very large variety of curves is finally derived from two simple algebraic equations for each series, viz.: For Series 1, Eqs., (9) and (10) § 23, and for series II, Eqs. (11) and (12), § 24. The first equation of each series is the differential equation of the second equation of that series,

1. Prof. H. J. Ryan and Mr. M. E. Thompson on "A Method for Preventing Armature Reaction." TRANS. AM INST. EL. ENGRS., March, 1895.

but the integration required to pass from the first to the second is already performed, the equations are complete and may be utilized at once by simply substituting numerical values.

§ 37. To obtain the watts, it is first necessary to know the elements of a curve representing the momentary current and the phase of the current in relation to the machine E. M. F. Methods based on the resistance, inductance and capacity of a circuit have already been employed to determine the phase relation of the current and the impressed electromotive force, when distribution caused by hysteresis, etc., was not considered, and as the present paper is confined to the explanation of a method of developing certain equations and ascertaining from those of E. M. F. and current the work done in watts, such purpose may be accomplished by assuming that the current curve is of the same form as the curve of E. M. F. as is customary, and developing a method to determine the influence of changes of phase, with the under-

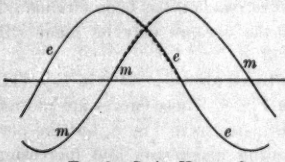

FIG 6.—Series II, $u = 2$.

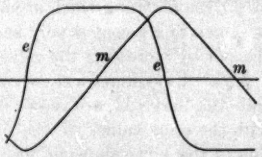

FIG 7.—Series II, $u = 6$.

standing that for the purposes of this paper the phase angles are to be ascertained by methods at present in vogue.

§ 38. It is assumed as evident that the work derived from an alternating electric circuit for a particular apparatus must equal the product of the momentary E. M. F. at the main terminals and the momentary main or primary current flowing through such apparatus, which puts the calculations for momentary values on the same basis as for direct current. In Fig. 9 the ordinates of the curves e and c are intended to show the momentary values of the machine E. M. F. and of the primary current respectively. The ordinates are plotted in the scale of 10 and are to be corrected finally by arithmetical coefficients given in § 18. According to our conception that the time development is illustrated by an ordinate moving positively or to the right, the phase of the current c is behind that of the E. M. F. e because the maximum value of the former is reached later. The distance

along the time axis $O\,N = k$ is called the difference in phase, which has a maximum value s and is expressed in the same scale. The difference of phase referred to generating radii, as in Fig. 1*a*, equals "the angle of lag," the value of which is $\varphi = k \div s \times 90°$.

§ 39. When $k = 0$ the current and electromotive force are in phase with each other, so that $w = e\,c = e^2$. Integrating the squares, either of the value of e in Eq. (11) or by substitution in Eq. (23) hereafter developed and dividing by the maximum ordinate, we have the mean square which is the value w_1 of the watts with e and c in phase. The square root of this, designated $\sqrt{\text{mean}^2}$, gives the effective voltage or current for curves of different forms.

§ 40. The mean square values for all of the representative curves developed depend entirely upon the variable exponent, and are connected with the same by a very simple relation. The general equation is:

$$\sqrt{\text{mean}^2}\, e = \left(\frac{1}{s}\int_0^s e^2\, d\,x\right)^{\frac{1}{2}}. \tag{13}$$

For e_1 in Eq. (9).

$$\sqrt{\text{mean}^2}\, e_1 = \left[\frac{1}{s}\int_0^s \left(\frac{1}{s^{v-1}}\, x^v\right)^2 d\,x\right]^{\frac{1}{2}} = s\left(\frac{1}{2\,v+1}\right)^{\frac{1}{2}}. \tag{14}$$

For e in Eq. (11).

$$\sqrt{\text{mean}^2}\, e = \left[\frac{1}{s}\int_0^s \left(s - \frac{x^u}{s^{u-1}}\right)^2 d\,x\right]^{\frac{1}{2}} \tag{15}$$

$$= s\left(1 - \frac{2}{u+1} + \frac{1}{2\,u+1}\right)^{\frac{1}{2}}.$$

§ 41. The average diagram watts w_1, § 18, for e and c in phase are represented by the square of the mean² value, hence for a sine curve, or the substantially equivalent curve for which $u = 1.781$, mentioned in § 32, $w_1 = 7.071^2 = 50$ out of a maximum of 100 which would be obtained if a rectangular curve of E. M. F. were possible.

§ 42. If for the present investigation we assume $u = 2$ in Eq. (11), the resulting curve e, as shown in Fig. 6, § 31, is a parabola, which, as stated, has a little greater area than a sine curve, the $\sqrt{\text{mean}^2}$ value being 7.303 and the average of the diagram watts for $k = 0$ or e and c in phase is $w_1 = 53.33$.

§ 43. When $k = s = 10$, making the lag equal one-quarter period, the diagram watts due to the exciting current can be calculated with comparative ease, as will be explained hereafter. When, however, the phase is between zero and s considerable detail work is necessary to perform the integrations, for the reason that the equations are only applicable between the limits plus and minus s. The positive and negative branches are symmetrical between these limits, but beyond, in either direction, the curve rapidly changes, developing infinite positive and negative branches.

§ 44. Either of the curves e or c, Fig. 9, may be generated

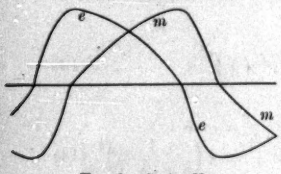

FIG. 8.—Series II, $u = 2$. (Distorted.)

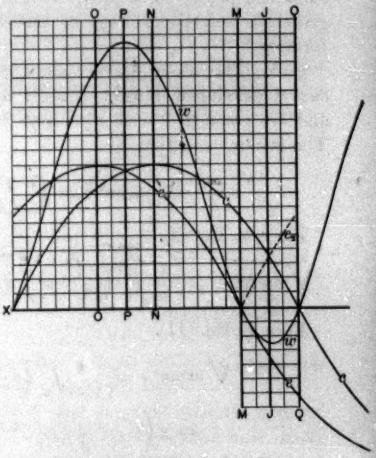

FIG. 9.—Series II, $u = 2$. $K = 4$.

from Eq. (11) by making the origin at the maximum value of the curve in each case. In order, however, to formulate coincident momentary values, it is necessary that both curves be referred to the same origin. This is accomplished by giving separate designations to the "generating abscissa" or those necessary to generate the two curves, and stating the values of the same in terms of a general abscissa, x.

§ 45. In addition to previous notation let:

x = generating abscissa of curve e of E. M. F.

x_c = generating abscissa of curve c of current.

x = variable abscissa with zero at the origin assumed.

Also as already mentioned, §38, let:

k = "difference of phase."

§ 46. The equations of E. M. F. and current for $u = 2$, after substituting the generating abscissa as above in Eq. (11), take the following general form:

$$e = \frac{1}{s}\left(s^2 - x_e^2\right). \tag{16}$$

$$c = \frac{1}{s}\left(s^2 - x_c^2\right). \tag{17}$$

§ 47. Fig. 9 represents curves e and c of E. M. F. and current plotted in a scale of 10 units per quarter period, as per § 14, with current lagging 4 units or 36° per § 38, behind the E. M. F., shown by the fact that a time ordinate moved clockwise would reach the maximum ordinate of diagram current later than that of the maximum E. M. F. It is convenient to fix the origin at ordinate O, O, the maximum value of the curve of E. M. F., when the ordinates of curve e for a quarter period from O to M, Fig. 9, will be developed by simply making $x_e = x$ in Eq. (16) as shown in Eq. (18). Between the limits M and Q if $x_e = 2s - x$ in Eq. (16), as shown in Eq. (19), the ordinates of the resulting curve will be positive, as shown by curve e_2, Fig. 9, and give the same numerical values as if negative, with the advantage that in multiplying together the ordinates of e and c to obtain the diagram watts between these limits, the annoyances due to changes of sign when multiplying by a negative variable are overcome. The result should, however, be made minus, as evidently the diagram watts between the limits are minus. (See § 53).

§ 48. The ordinates of the curve c will be developed from the same origin, O, with due allowance for lag by making $x_c = k - x$ in Eq. (17) between limits O and N as shown in Eq. (20) and $x_c = x - k$ between limits N and Q, as shown in Eq. (21).

§ 49. The several equations then take the following form:

Between ordinates O and M

$$e = \frac{1}{s}\left(s^2 - x^2\right). \tag{18}$$

Between ordinates M and Q

$$e = \frac{1}{s}\left(s^2 - (2s - x)^2\right). \tag{19}$$

Between ordinates O and N

$$c = \frac{1}{s}\left(s^2 - (k - x)^2\right). \qquad (20)$$

Between ordinates N and Q

$$c = \frac{1}{s}\left(s^2 - (x - k)^2\right). \quad \text{(See § 56.)} \qquad (21)$$

§ 50. Evidently for symmetrical curves the average ordinates of a watt curve for a single period or any number of periods, equals the average ordinate of a quarter period between the limits shown by the ordinates P and J, for which in this case $x = 2$ and 12 respectively.

§ 51. The values of the ordinates of the curves e and c between limits O and J as calculated from the above equations are given in Table 1. The right-hand branches of the curves shown in Fig. 9 are plotted from the ordinates as calculated for $u = 2$, $s = 10$ and $k = 4$, it being observed that the general value of x for Eqs. (19) and (21) is applicable between $x = 10$ and $x = 14$. The left-hand branches are constructed in the opposite direction from the same ordinates. There are also given in the last column of Table I. the products of the several corresponding ordinates $e\,c = w$ or the momentary diagram, watts developed, which are also plotted in Fig. 9 outlining a curve w. The ordinates of curve w are in a scale of 100, but are plotted on one-fifth of this scale for convenience of illustration.

§ 52.

TABLE I.

SHOWING VALUES OF GENERAL AND GENERATING ABCISSA AND CORRESPONDING ORDINATES OF CURVES e AND c IN FIG. 9. $u = 2$, $k = 4$.

Ordinates.	x and x_c	e	x_c	c	$e\,c = w$
O	0	10.0	− 4	8.4	84.00
	1	9.9	− 3	9.1	90.09
P	2	9.6	− 2	9.6	92.16
	3	9.1	− 1	9.9	90.09
	4	8.4	0	10 0	84.00
	5	7.5	1	9.9	74.25
	6	6.4	2	9 6	61.44
	7	5.1	3	9.1	46.41
	8	3.6	4	8.4	30.24
	9	1.9	5	7.5	14.25
M	10	0.0	6	6.4	0.00
	11	− 1.9	7	5.1	− 9.69
J	12	− 3.6	8	3.6	− 12.96

§ 53. The work delivered to the apparatus by the generator is represented by the positive branch of the curve developed when e and c are of like sign, but this is ordinarily diminished by the smaller area of the negative branch of the curve when e and c are opposite in sign, this small amount of work representing the energy returned to the line by the apparatus.

§ 54. Evidently the area of the watt curves, and, therefore, their average height, can be obtained approximately from the calculated ordinates, and by increasing the number of such ordinates or plotting a curve from those already stated and using the planimeter, still more accurate results can be obtained. It is gratifying to state, however, as indicated at the outset, that absolutely accurate results may be obtained by combining and integrating the equations. The operation, though not at all difficult, is a little tedious on account of the number of terms which are developed by expanding the binomials, multiplying together the equations of e and c and integrating the resulting terms. By this method, however, it is possible to obtain as accurate results with curves of various forms as can be obtained by the mean square and difference of phase method with sine curves.

§ 55. If we multiply together Eqs. (18) and (20), member by member, we obtain an equation of the momentary value of the diagram watts between limits to be explained.

$$e\,c = w = \frac{1}{s^2}\left(s^4 - s^2\,k^2 + 2\,s^2\,k\,x - 2\,s^2\,x^2 + k^2\,x^2 - 2\,k\,x^3 + x^4\right). \tag{22}$$

Integrating we have:

$$G = \int y\,d\,x = \frac{x_1}{s_2}\left(s^4 - s^2\,k^2 - s^2\,k\,x - \frac{2\,s^2\,x^2}{3} + \frac{k^2\,x^2}{3} - \frac{k\,x^3}{2} + \frac{x^4}{5}\right). \tag{23}$$

§ 56. From the limits expressed in relation to the equations in § 49, Eqs. (22) and (23) above would appear to be applicable only between ordinates O and N, but since $(k - x)^2$ equals algebraically $(x - k)^2$ (although $k - x$ does not equal $x - k$), Eqs. (22) and (23) are really applicable between ordinates O and M, being limited by the value of e, Eq. (18) instead of the value of c. Eq. (22) may be employed to obtain either of the ordinates of the watt curve or the same may be obtained as in Table I, by first determining the corresponding ordinates e and c separately from the equations in § 49 and multiplying them together.

§ 57. An integration of the watt curves between ordinates P and M is readily obtained from Eq. (23) between the limits, $x = 2$ and 10 respectively.

The value of the integrals will be found to be as follows:

	G .	w_1
Between limits O and M, $x = 0$ and $x = 10$	626.67	62.67
Between limits O and P, $x = 0$ and $x = 2$. Deduct	178.84	89.42
Between limits P and M, $x = 2$ and $x = 10$	447.83	55.98

§ 58. The average of the diagram watts between the same limits equals the area divided by the base and is therefore:

$$w_1 = G \div x_1. \tag{24}$$

In the second column above are given the values of w_1 for each integration.

§ 59. The next step is to develop, by multiplying together Eqs. (19) and (21), member by member, an equation corresponding to Eq. (22), the integral of which G, corresponding to Eq. (23), will be found to be as follows:

$$G = \int y\, d\, x = \frac{x_1}{s^2}\left(-3\, s^4 + s^2\, x^2 - 3\, s^2\, k\, x + 3\, s^2\, k^2 + 2\, s^3\, x - s\, x^3 + \frac{8\, s\, k\, x^2}{3} - 2\, s\, k^2\, x - \frac{s^2\, x^2}{3} + \frac{k^2\, x^2}{3} - \frac{k\, x^3}{2} + \frac{x^4}{5}\right). \tag{25}$$

which is appliciple between ordinates M and Q.

§ 60. The values of the integral and average diagram watts between ordinates M and J, $x = 10$ and 12 respectively, on the basis that this integral is minus (see § 47 and § 53) will be found to be as follows:

G	w_1
−17.18	−8.59

§ 61. Adding the integral algebraically to that previously obtained, § 57, we have for the total integral for one-quarter period between ordinates P and J for $u = 2$, $k = 4$ ..... G = 420.65, w_1 = 43.065

§ 62. When $k = 10$ the current lags one-quarter phase behind the electromotive force, and but one integration is necessary viz.: the one first described where Eqs. (18) and (20 are combined, for the reason that the maximum current indicating its

phase will have shifted to ordinate M or $k = 10$, and a complete integration for a whole quarter period is obtained by making $x = 10$ in Eq. (23). The result of the integration for e and c at one-quarter phase or 90° apart will be found to be $w_1 = \pm 36.67$.

§ 63. For $k = 0$ or e and c in phase $w_1 = 53.33$ derived from the $\sqrt{\text{mean}^2}$ value as given in § 42. The same result will be obtained by substituting $x = 10$, $k = 0$ in Eq. (23).

§ 64. Recapitulating, then, we find that for $k = 0$, or e and c in phase, § 63, $w_1 = 53.33$; for $k = 4$, § 61, $w_1 = 43.065$, and for e and c in quadrature $k = 10$, § 62, $w_1 = \pm 36.67$, the maximum possible being 100 as previously stated. The result for $k = 10$ represents watts for excitation. In general the apparatus is so proportioned that under these conditions the actual energy in the circuit is relatively much less in proportion than the diagram watts above stated, which are also to be corrected by the introduction of the coefficients for reducing diagram values to commercial units stated in § 18. These watts are of contrary sign every alternate quarter period.

§ 65. It should be borne in mind that the above illustrations apply only to one of the very many forms of curves which may be obtained by varying the value of u in the equations given, and for each of these curves the diagram watts may be found directly, for any desired difference of lag, without resorting to the suggestion recently made of reducing unusual curves to what are called "equivalent sine curves."

§ 66. Evidently, moreover, it is possible to use a different function for descending and ascending branches of the curves, thus producing unsymmetrical curves somewhat like those in Fig. 8 (see § 35) and yet perform the integrations, and this function may be developed by imposing upon the original function another function based on the actual conditions which produce a certain change, so that the curves finally resulting will include all of the conditions. It has been pointed out that the observed distortions may be illustrated by imposing upon the primary function a series of harmonics. To make such a method strictly rational it must be shown that each condition if formulated would produce the equation of such a harmonic. It is not probable that such is the case, but fortunately the present method gives facilities for considering the additional conditions whatever the general shape of the curves that will represent them.

§ 67. It is to some extent unfortunate that the equations se-

lected do not cause the curves to reverse direction periodically, and that the necessity of integrating between limits, and somewhat changing the forms of equations for different limits makes considerable detail work necessary to obtain the integrations, but on the other hand *it is very gratifying that integrations can be obtained at all* of quantities which so closely represent *actual* rather than assumed conditions. The paper deals with instantaneous watts derive from instantaneous values of electromotive force and current in the same way that similar deductions are made for direct current. The methods described of reducing final results from such values, though developed with considerable labor, involve only mathematics of the simplest order, which can readily be corrected if mistakes have been made, and cannot apparently give rise to any difference of opinions as to principles involved.

§ 68.

TABLE II.

DISTINGUISHING FEATURES OF THE DIFFERENT CURVES.

General Shape of Curves of E. M. F. and Current.					Diagram Watts in Scale of 100 e and c in phase.	$\sqrt{\text{mean}^2}$ in Scale of 10.	Relative Ratios Max. to Effective Voltage.
Triangle	Series I	$v = 1$	§ 25	Fig. 4	33.333	5.774	1.732
	" II	$n = 1$	§ 29				
Sine Curve	—	—	§ 32	" 1	50.000	7.071	1.414
Approximate Sine Curve.	Series II	$n = 1.781$	§ 32	—	50.000	7.071	1.414
Parabolic Curve	" II	$n = 2$	§ 31	Fig. 6	53.333	7.303	1.369
Approximate Rectangle.	" II	$n = 6$	§ 34	" 7	79.120	8.895	1.124
Rectangle	" I	$v = 0$	§ 25	" 2	100.00	10.000	1.000
	" II	$n = \infty$	§ 33				

§ 69. In Table II. are presented the mean square values and ratios of maximum to effective voltage for a number of curves shown in the various figures, together with references to the partial exponents, the figures and the sections where the curves are described. It appears that the most desirable curve for lighting purposes would be a rectangle if the same were practicable. The approximate rectangle shown in Fig. 9 can probably be obtained with alternating current machines designed for the purpose. This curve would also give greater power than forms with less

area, but it is not probable that the magnetism could be reversed with sufficient rapidity to secure proper reactions between the field and armature.

§ 70. It is thought that for power purposes the increment or decrement of magnetism which produces the E. M. F. should be constant, which condition would secure the maximum time possible for each momentary change in magnetism. The second differential coefficient of a parabolic curve is constant, so our first impressions were that the curve of E. M. F. should for power purposes be a parabola, but on further consideration it appears that, since it is the increment of change in magnetism which should be constant, the curve of E. M. F. should be a triangle and the curve of magnetization a parabola, as shown in § 29 and Fig. 4. The second differential coefficient of the equation of magnetization, which equals the first differential coefficient of the equation of E. M. F. represents the increment which should be constant. As the curve m passes through zero, its tangent, and consequently the E. M. F., is a maximum, the second differential coefficient of m changes sign and becomes a decrement, and as the time ordinate moves from left to right, the tangent to the curve m or the E. M. F. is decreased. Making this decrement equal to a constant, we have:

$$\frac{d\,m^2}{d^2\,x} = \frac{d\,e}{d\,x} = -\,a\,. \qquad (26)$$

Integrating we have the indefinite integral of the tangent to the curve of magnetization which equals the electromotive force, and finding the value of the constant of integration, C, from the condition that when $x = s$, $e = 0$, we have the corrected integral as follows:

$$\frac{d\,m}{d\,x} = e = C - a\,x = a\,(s - x). \qquad (27)$$

Hence the rational form of the curve of E. M. F. for power purposes is a triangle, if it be accepted as desirable that the maximum time should be allowed for each magnetic change. Integrating again we have:

$$m = a\left(s\,x - \frac{x^2}{2}\right), \qquad (28)$$

which is the equation of a parabola, as in Fig. 4, and is in the same form as Equation (12), with the exception of the arbitrary co-

efficient assumed for this case. The astonishing feature of this part of the investigation is the remarkably small difference in the curve of magnetization required to cause the curve of E. M. F. to pass from a sine curve to a triangle. When e is a sine curve, m is also a sine curve, but when e is a triangle, m is a parabola, as in Fig. 4, and the difference between a sine curve and a parabola is only that between the dotted and drawn line of the curve e in Fig. 6, and variations of this small difference applied to a curve of magnetization will make all the difference between sine and pointed curves. The objection to a triangular curve of electromotive force is the additional strain that it imposes on the insulation on account of the high relative ratio of maximum to effective voltage. (See last column, Table II., § 68.) Ordinarily a pointed curve would be used, resembling a triangle with a rounded point, which it will be seen by comparing Figs. 4 and 6 would result from Equations (11) and (12, for values of u between 1 and 2. This question cannot be fully settled mathematically without considering modifications due to transformation, but the general principle is well worthy of careful consideration.

§ 71. The author is indebted to Prof. Harris J. Ryan for valuable suggestions during these investigations, though the professor has had no opportunity to examine the complete paper or to criticise the views of the writer in detail.

[For discussion see page 591.]

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th, 1895. President Duncan in the Chair.

NOTES ON THE RECONSTRUCTION OF A SMALL CENTRAL STATION PLANT.

BY FRANKLIN L. POPE.

The financial condition of the smaller central station electric lighting plants throughout the country is at the present time by no means satisfactory, and in too many instances cannot even be truthfully said to be encouraging. A survey of the field shows that very few such plants located in towns having less than 10,000 inhabitants are earning more money than is necessary to meet their operating expenses and to provide for indispensable current repairs. In the state of Massachussetts, in which the operations of all electric lighting companies are by law made a matter of public record, it appears from the latest reports that the aggregate liabilities of the fifty-seven companies operating in that state, including stocks, bonds, and floating indebtedness, amounted on June 30, 1894, in round numbers to $14,000,000, nearly all of which stands charged to construction account. The net earnings for the preceding year were $1,000,000, or about 7.1 per cent. on the total investment: a sum obviously quite insufficient to provide for depreciation and at the same time pay a fair dividend on the capital which has gone into the business. But if half-a-dozen of the larger plants, in cities like Boston, Lowell, Worcester, Springfield, Lynn and Fall River were excluded from the list, the showing for the smaller plants would be even far worse than it now appears.

Many of these small plants were started at an earlier day than could have been justified by any reasonable estimate of the business then in sight, and now find themselves hampered by inconvenient buildings, and with unsuitable machinery bought at high prices,

and encumbered with defective business methods which experience has shown to be wholly inconsistent with the dictates of good judgment.

With the owners of many of these plants, it has become a very serious question whether the easiest way out of the dilemma which confronts them, may not be to relegate the entire plant to the junk-shop and the scrap-pile, and commence over again with new buildings, modern machinery and improved methods of administration. When the necessary capital is readily forthcoming, there can be no doubt that this would often be the wisest course of procedure, but for obvious reasons, it is one which is not always, nor even usually practicable. The alternative is to remodel the existing plant, bringing it as nearly as may be into accordance with the best modern practice, and utilizing so far as possible, the old material; a course which at least has the merit of avoiding an undue expansion of the construction account, in most cases already sufficiently burdensome.

Having been called upon during the past year to advise the owners of a plant of the character above referred to, in reference to certain changes which had been suggested as desirable, and having afterwards been employed in a professional capacity to design the work and superintend its execution, I have thought that some account of what we undertook to do and how we did it, might not be without interest to the members of the INSTITUTE.

The Great Barrington (Mass.) Electric Light Company was organized and commenced business in 1888. The population of the district intended to be served was about 3,000, and most of the expected consumers were located within 2,000 feet of the point decided upon for the station. This was built of wood in the most inexpensive manner possible, and was placed alongside the railroad for convenience in receiving coal, although at the same time the danger from fire was materially increased. The original outfit was an Edison 3-wire, equipped with a pair of 250-light 110-volt dynamos, and the company commenced business with 281 lights on contract at $10 per year each; wiring free. The center of distribution was 1800 feet from the station, necessitating over a ton of copper in the feeders alone. Generally speaking, the plant was well laid out, and well built as things went in those days. The two dynamos were belted to a single 80 H. P. Armington and Sims engine. The original cost of the plant was about $16,000. The following year a Schuyler are-

plant for street-lighting was added, carrying 35 arcs, nominally of 1,500 C. P., which was run from the same engine and boiler. In 1890, the plant was considerably enlarged by the addition of a second arc machine, a Westinghouse 500-light alternator, and a second engine and boiler of the same capacity as the first. An 80 K. W. Westinghouse dynamo of more modern type was afterwards substituted for the original one.

Upon examining the plant last year, I found the Edison machines carrying on Saturday evenings a maximum load of some 450 lights, while three evenings in the week (with the stores closed) it fell to perhaps half that amount. The two Schuyler machines, with an aggregate capacity of 55 to 60 lights were carrying about 38 to 40, or an equivalent of that amount, while the Westinghouse machine was seldom as much as half-loaded, carrying a maximum of possibly 500 lights during three or four months of the summer season, and not much more than one-fourth that amount the remainder of the year. Necessarily, with so many dynamos of different types, and with such a variable, yet small average output, the consumption of coal was excessive as compared with the light delivered and paid for.

The street lines, according to the usual practice, were of No. 6 B. & S. weather-proof wire; the poles were of cedar, of good size and fitted with pine or spruce cross-arms, with common green glass insulators set upon wooden pins. In consequence of a silly prejudice, which had been fomented amongst the citizens by interested parties against permitting poles to be set in the streets, the wires, in a very great number of instances, had been attached, by cross-arms or brackets, to the trunks of the immense elm trees with which the streets of the town were shaded; a practice which occasioned an enormous loss of current every wet night as well as much irregularity in the performance of the lights. The effect on the trees was by no means salutary, while the appearance was as much worse than that of poles in the streets as could possibly be imagined.

The village of Great Barrington extends for the most part along a single broad thoroughfare for a distance of nearly three miles, and the street-lighting circuits are consequently very straggling. The 1500 C. P. lamps, which were suspended at intervals of 800 to 1,000 feet, were actually of very little service in illuminating the densely shaded streets.

After a careful consideration of the situation, keeping in

view the greatest possible reduction of present and future operating expenses, it was determined the wisest course to pursue would be to consolidate the whole service so that it could be supplied by one dynamo, in place of five underloaded ones. In pursuance of this plan it was decided to adopt the two-phase alternating system, at a maximum pressure of 2100 volts in the primaries, and 105 volts in the secondaries, with a frequency sufficiently low to permit the advantageous use of induction motors if required. It was furthermore decided to abandon the steam plant, and to make arrangements to utilize some one of the excellent water-powers which were available within practicable distances. Under ordinary circumstances, I should have hesitated to recommend the substitution of water-power for steam as the sole source of power for the operation of an electric lighting plant. Water-power is an invaluable auxiliary, and when conveniently available for use in conjunction with steam, may often be made to save a very large coal-bill in the course of a year. On the other hand, the excessive fluctuations to which it is subject— which are scarcely realized by those but casually acquainted with the subject— render it in most cases a very uncertain reliance for a business which is compelled to go on, perforce, every night in the year, and which cannot suspend operations, as an ordinary manufactory does, if worst comes to worst, for a week or two at a time. Even a water-privilege which, during ten months of the year, furnishes twice as much power as is needed, and even more, may be expected to fall off, during one of the extraordinarily dry seasons which occur at intervals of from five to ten years, to one-third its usual amount. In such a case, an electric plant solely dependent upon water-power would find itself in a most undesirable predicament.

In the present instance, the choice of a water-privilege finally reduced itself to two sites, one in the town itself, within half a mile of the center of consumption, and the other at Glendale village, seven miles distant, both situated on the Housatonic river. The privilege first mentioned being already occupied by a woolen factory, only the surplus water was available, but this was known to be quite sufficient for the requirements of the electric company at least nine months in each year, leaving three months to be run by steam. It had the advantage of being close at hand, and was capable of being fitted up at a moderate cost. As to the Glendale privilege, it was necessary to be very

sure that the lowest water of a dry summer would give all the power required to run the plant without the aid of steam. Having invariably found the value of a water-power to be greatly exaggerated, not only in popular estimation, but in the opinion of its owners, the matter was investigated with much care. From the official state map of Massachusetts, it was ascertained that the area of the drainage basin of the Housatonic above the Glendale dam was 269 square miles. J. T. Fanning, a leading authority, from an extended examination of the recorded observations on the rainfall and flow of the New England rivers, reaches the conclusion that a water-shed of the area mentioned, may be estimated to yield the quantities of water given below:—

CUBIC FEET OF WATER PER SECOND PER SQUARE MILE.[1]

Minimum (15 days of least summer flow)	0.25
Mean (120 days, usually July to October inclusive)	0.90
Maximum (flood volume)	80.00

It will be noticed that the flow in extreme dry weather is less than one-third of that which may ordinarily be depended upon through the remainder of the year.

The distribution of rainfall throughout the year should be studied. It is often materially modified by local geographical conditions. The diagram shows that the distribution on the head-waters of the Housatonic is quite different from the normal type of the northeastern region. The same may be true of other rivers.

While this investigation was going on, it was discovered that actual measurements of the volume of water in the Housatonic river had been made in 1878 by the engineers of the New York Department of Public Works, with reference to its utilization as a future source of water supply for that city. The minimum summer flow was found to be (as given in the engineer's report), 0.34 c. f. per second per square mile. It was also learned that measurements made on several different occasions at Birmingham, Conn, in very low stages of water, gave an average of 0.32 c. f. per second per square mile. It was therefore assumed that Mr. Fanning's estimates were at least on the safe side. The greater volume of water found by the actual measurements, is doubtless due to the fact that there are some 5 or 6 square miles of reservoirs, consisting of natural and artificial lakes, on the upper wa-

[1] Hydraulic and Water Supply Engineering. (3d ed.), p. 75; table 19. New York, 1883.

ters of the Housatonic, which are drawn upon by the numerous mills on the river as an extra supply during the season of drought.

A minimum flow of 0.25 per second per square mile would give at Glendale, 4035 c. f. per minute. Multiplying this by the weight of a c. f. of water (63.3 lbs.) gives 255,415 foot-pounds, which, divided by 33,000 gives 7.74 gross horse-power per foot of fall, or a total of 99.6 H. P. for the 13 feet fall at Glendale. The average efficiency of a good turbine may safely be taken at 75 per cent. which would give 67.9 as the available H. P. during the whole 24 hours, in time of lowest water. In electric lighting however, the great bulk of work is done within a period of about 4 hours (in summer time), and hence it is possible, in case there is sufficient area of pondage above the dam, to increase this capacity

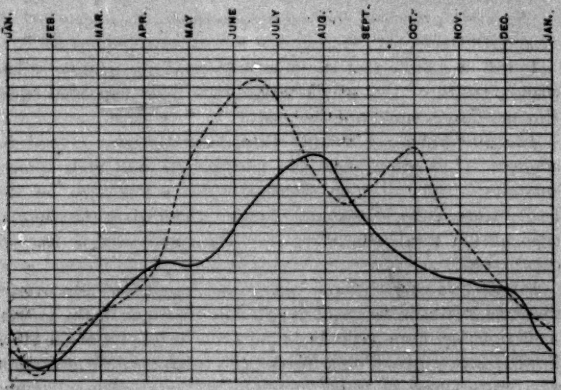

FIG. 1.—Curve of mean annual distribution of rainfall. Full line is reduced observations at Williamstown, Mass., 1816 to 1874. Dotted line is mean of all observations in the Hudson and Champlain valleys, and northern and western New York, aggregate 564 years. From Schott's Rainfall Tables, pp. 199, 251. Washington, 1881.

by storage at least four-fold, which would raise the limit of minimum available power during lighting hours, to 271.6 H.P.; an amount which was considered to be ample to meet all the probable requirements of the Great Barrington plant for many years to come.

While negotiations were still pending with the owners of the Glendale privilege, and also the one in the village already referred to, overtures were received from a manufacturing company owning a third exceptionally desirable privilege, on the

same stream, at an intermediate point considerably nearer than Glendale. This company had only recently completed a new dam, head-gates, raceways, etc., at a very considerable expense, and was willing to lease the complete establishment, including a new McCormick turbine of 325 H.P. and a two-phase Stanley generator of corresponding capacity, at a monthly rental based upon the actual output as measured in kilowatt-hours at the dynamo terminals, provided that a certain minimum monthly consumption was guaranteed. With the same volume of water as at Glendale, the fall at this point was 20 feet, assuring at least 417 H. P. at lowest water, during lighting hours. All the hydraulic appparatus and appointments were of the best possible construction, and well-calculated to ensure absolute permanency of operation.

The minimum rental exacted was somewhat less than the amount of the coal-bill of the Great Barrington company for the preceding fiscal year, but while the immediate saving in operating expenses was not large, the acceptance of the proposition would place the company in a position to reduce its rates to consumers, for the reason that its output might be very largely increased without materially augmenting its operating expenses. A lease for a term of years was accordingly closed.

In laying out the plant it was determined to bring the main feeders directly to a distributing station in the village, to be used principally as a convenient headquarters for testing the circuits and controlling the street-lighting service. In laying out the transmission line, a surveyor was employed, and a preliminary line was run directly from the power-house to the distributing station. The air-line distance was found to 5.15 miles. With the assistance of the surveyor, the actual line was then staked out, going directly across country, and keeping as near as circumstances permitted to the transit line. About half the distance, the transit-line was found to so nearly coincide with existing highways, that the consent of the local authorities was obtained to set the poles along the highway location; the remainder of the route lay principally through uncultivated land of little value, so that a comparatively small expenditure was sufficient to secure a release from all claims for land damages. This enabled the line to be located with long stretches absolutely straight, avoiding all sharp angles; a very important consideration when heavy wires are used. The poles were of selected chestnut with natural butts.

usually set five feet in the ground at maximum intervals of 125 feet. The poles were ordinarily 25 feet long and 8 inches thick at the small end. Shorter poles were sometimes used on elevations and longer ones in depressions, in order to equalize the strain as much as possible. The insulators used were of the large double-bell white porcelain type (German government standard), and were imported by us from Hagen. The insulator of the top wire is set upon a malleable-iron stem 14 inches long screwed into the top of the pole which is tapered to 5 inches diameter and protected from splitting by driving on a wrought-iron ring. The tapered part of the pole, as well as the top, was given a coating of mineral paint mixed as thick as it could be spread with a brush. The insulator of the second wire is carried on a malleable-iron goose-neck, screwed into a $\frac{3}{4}$ inch hole bored in the side of the pole, in such position as to bring the wires about 16 inches apart. Another hole was bored on the opposite side of the pole, intended to take the goose-neck of the third wire at some future time, leaving the same interval between the second and third wires. The porcelain insulators are fixed to their iron supports by a packing of oakum placed between the screw-threads, which serves to prevent any danger of fracture by expansion or contraction. The line-wire is laid in a groove formed in the top of the insulator, except upon the curves and angles, in which case it is tied at the side in a circumferential groove, as is usual in this country. The German method of tying is quite complex, and unnecessarily strong; in case of undue strain, if anything gives way it had best be the tie-wire. We therefore devised a simple tie which was easily and quickly applied, and which has so far served an admirable purpose. We were obliged to string the wires during very cold weather; sometimes as cold as 8 or 10 degrees below zero, and hence it was necessary to strain them very tight. A block and fall and a well-trained horse were used in pulling up, usually six or seven spans of one wire at a time. The hook of the block was was always attached to the copper wire, whether bare or insulated, with a chain-knot made of $\frac{3}{4}$ inch rope. The feeder-wires were of No. 3 B. & S. soft copper, covered with weather-proof "insulation" along the highway (as a concession to enlightened public opinion), but elsewhere bare. The lengths of wire were joined with McIntire twisted couplings; the unusual strain we had to put upon them occasionally pulled one apart, and this led us, out of abundant caution, to solder them, although this was done for

mechanical rather than for electrical reasons. Only two feeder wires have as yet been strung, providing for a single-phase current from one side of the two-phase generator, but it is the intention to run a third feeder at an early day, which will enable two-phase induction motors to be connected to the same distributing system.

A pair of telephone wires of No. 12 steel were strung below the feeder-wires, and these were supported upon small German porcelain insulators on iron goose-necks on opposite sides of the poles. These wires were transposed at intervals of about a mile, in order to eliminate the inductive effects of the alternating current in the feeders. The feeder-lines were carried under the railroad at an undergrade crossing by placing the insulators upon iron brackets leaded into the stone abutments. The plan of construction above described makes a strong, handsome and durable line, while the insulation of the circuit even in the worst of weather, is simply faultless.[1]

The system has been planned to deliver the current at the distributing station at a uniform pressure of 2,100 volts. Two distributing centers were fixed upon in the old Edison 3-wire network, and at each of these points a pair of large transformers, having a ratio of 20 : 1, were fixed upon a pole, with their respective primaries in series between a pair of branch feeders from the distributing system, and their secondaries were coupled in series in like manner with the neutral wire between them. None of the consumers on the old Edison system knew when the change had been made to the new service from anything they were able to notice in the behavior of the lights.

1. I regret that I am unable to present any actual measurements of the insulation of the line of the Great Barrington company, no opportunity having occurred since the work was completed, of making tests under atmospheric conditions of minimum insulation. Several years ago, however, while engaged in telegraphic service, I made a series of nearly 100 separate tests in rainy and foggy weather, extending over a period of five years, of a set of 10 porcelain insulators of the same make and pattern in every particular as those now on the Great Barrington line, erected on a house-top in the city and therefore much exposed to smoke and dirt. These measurements gave a mean resistance of 28.3 megohms, and a minimum resistance of 19 megohms per insulator. On a metallic circuit therefore, the minimum insulation resistance at each pole would be 38 megohms. On the Great Barrington line of 28,260 feet there are 250 poles and other supports, and hence we may assume that the minimum resistance of the insulation of the circuit as a whole would be 152,000 ohms. The current loss by leakage is found by dividing the mean voltage by the insulation resistance; $\frac{2,200}{152,000} = 0.014$ ampere; an amount too small for serious consideration. The conductivity resistance of the feeder circuit measures 9.07 ohms at 0° Centigrade (32° Fahr.)

The next thing done was to reconstruct the street-lighting system. In place of the 36 arcs of 1500 nominal C. P. formerly in use we substituted 126 incandescent lamps of 50 volts and 32 C. P., placed in Iona fixtures projecting horizontally from the poles 14 feet above the ground. The lights, as a rule, were fixed upon every alternate pole, but in the business center, the street being broad, they were placed on each side at intervals of about 250 feet, and staggered, so as not to come opposite each other. A Shallenberger shunt cut-out was applied to each lamp. The usual number of lamps in each circuit was 42, although we have since placed, in some cases, as many as 47 in one series without reducing the brilliancy of illumination sufficiently to be noticeable by any one but an expert. One end of each street-lighting circuit is joined to a special feeder leading to the sub-station, where it is connected with the main feeder through a knife-switch. The other end of each lamp-circuit is connected to any conveniently located branch feeder of the regular commercial lighting service. Each lamp-circuit has, or will have, a fuse-block and cut-out enclosed in a weather-proof box at each end, where it joins the opposite feeders. These 32 C. P. lamps, when run at full candle-power, furnish a most satisfactory illumination and give the streets a very attractive appearance. So far as possible, each lamp was located with the aid of a transit and level, so as to get them in absolutely straight lines both vertically and horizontally, a precaution which adds materially to the decorative effect. It is admitted by all that the streets of the town are much more satisfactorily lighted by the incandescents than they formerly were by arc lamps, while the actual cost to the company is considerably less. The new lamps were cut in, one at a time, on the old arc wires, jumpers being temporarily placed across the terminals until everything was in readiness to discontinue the use of arc machines.

One of the most marked advantages of the series street-lighting system, especially when shunt cut-outs are used, is its great flexibility and convenience. For example, instead of placing from 40 to 45 50-volt lamps in one series, we may use 20 to 23 100-volt lamps, or if an odd number be required, less than is necessary to make up a circuit, the deficit may be supplied by adding extra shunt-boxes in series at any convenient point in the circuit, until the pressure has been reduced to the required point. From time to time, as new lights are added, these spare shunt-boxes are one

after another brought into use in connection with them. Sometimes, also, we temporarily install extra street-lights by connecting them in parallel to the secondary mains of the regular commercial service, ultimately transferring them to new series circuits.

It has been found to be desirable to use a lamp of rather low efficiency for the street-lighting service, as there is always danger of leakage and short-circuits from wet boughs of trees and other objects getting into contact with the wires, and thus diverting an abnormal current through some portion of a lamp circuit. In such case, a lamp of high efficiency is pretty certain to be burned out, or at least to have its career of usefulness materially abridged. In this plant, the average consumption of energy in the street-lights, including lamps, lines, shunts, and leakage is found to be about 140 watts per lamp of 32 C. P.

Perhaps the most ticklish part of the whole undertaking was the changing over of the Westinghouse system, which was a 1050-volt primary and a 52-volt secondary, running at 16,500 alternations. In accordance with the new plan, it was of course necessary to double the pressure both in the primary and secondary circuits, and to substitute 104-volt for 52-volt lamps throughout. A preliminary test of one of the transformers demonstrated, that which perhaps might have been foreseen from theoretical considerations, viz.: that a dangerous quantity of heat was developed within a few hours when it was used to convert from 2,000 volts down to 100. In order to utilize, so far as possible, the old transformers, and at the same time avoid the above difficulty, various expedients were resorted to. Wherever a group of consumers was located in one neighborhood, a pair of large transformers was installed, with secondary mains extending from 500 to 600 feet in various directions; these transformers being of course placed in series with each other. Scattering consumers as far as practicable were united in pairs or small groups, and supplied by a pair of small transformers coupled in the same way. The Westinghouse meters, having been originally constructed for a frequency of 16,500 alternations, ran slow when the frequency was reduced to 8,000. The necessary coefficient for correction of the readings was easily ascertained by experiment, and as fast as possible the meters were fitted with new disks, supplied by the Westinghouse company at a trifling expense, adapted to the lesser frequency.

Of course it will be understood that the reason for resorting to these various shifts and expedients, was merely that we might utililize the old apparatus as far as it could possibly be done, and also that we might carry on the work of reconstruction, for the most part, with the ordinary working force of the establishment.

The horizontal double turbine which is used to drive the two-phase generator has done such good work that it deserves a few words of commendation. The selection of the best among the many available types of turbines for electric work is a matter which merits far more consideration from a scientific standpoint than it generally receives. Water-wheels, like dynamos and motors, are sometimes sold on commission by agents, and it not infrequently happens that the salesman who makes the largest "claims," especially if he sells his goods the cheapest, carries away the contract. It needs to be said, however, that there is a far greater difference than is often suspected, in the work that different types of wheels will do with a given, and especially a limited amount of water. There are, furthermore, a great many types of wheels in the market, which although as efficient as could be asked for with a full head of water, are very far from being so when the volume of water is reduced, even by a comparatively small percentage. It is but just to say that it is seldom that a turbine makes so favorable a showing, not only in this but in other respects, as the one provided by the company from which we lease our power. The following figures are selected from a much larger number obtained by actual measurement of its performance, in the testing-flume of the Holyoke Water-power Company.

Head acting on Wheel feet.	Revolutions per minute.	Quantity of water passing through Wheel (cu. ft. per sec.)	Horse-Power.	Per cent. of Efficiency.
16.56	135.25	83.56	124.22	79.25
16.60	136.25	81.75	124.50	80.99
16.80	155.00	70.79	109.37	81.18
17.02	154.50	63.42	95.86	78 39
17.06	136.75	52.19	73.42	71.95
17.44	152.25	42.55	53.71	63.90

These results are worthy of particular note, for the reason that they show a very high percentage of efficiency maintained through a wide range of variation in the quantity of water passing through the wheel; a most valuable characteristic for elec-

tric work. When the quantity of water used was diminished from 81.75 to 42.55 cubic feet per second, the percentage of efficiency fell only from 80.99 to 63.9, and what is even more remarkable, it was found that the efficiency remained well above 80 per cent. over a range of variation of discharge from 83.22 to 70 cubic feet per second, or 15.9 per cent. More than one type of turbine which enjoys a high reputation and extensive sale among power-users, will not reach 65 or even 60 per cent. efficiency at "three-quarters gate," while the 33" wheel above referred to has been found to give by actual test no less than 78 per cent. under similar conditions.

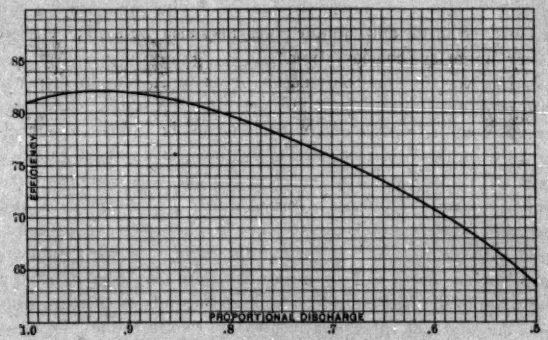

FIG. 2.—Efficiency Test of Jolly-McCormick Turbine.

The turbine carries upon its shaft a driving-pulley 100 inches in diameter, weighing 11,000 lbs. which serves as a balance-wheel. It is also provided with a Replogle electric governor operated by three cells of gravity battery, which has never failed to do its work quickly and certainly, even under trying conditions.

In carrying out this work, some things have been learned by experience which may be of use to others called upon to advise or to undertake the construction of similar works, and I will therefore venture to summarize some of my conclusions as follows:

1. In considering the advisability of operating an electric plant

by water-power, do not on any account neglect to ascertain from authentic sources of information, just how much water can be depended upon during the low stage in an extra dry year, *for this is the measure of its value for electric work* except when used as an auxiliary to steam. The ordinary estimates of the commercial value of a water-power are only too apt to prove preposterous exaggerations.

2. If rights-of-way or releases of damages can be obtained without too much trouble and expense, it is better to build the feeder line as directly across country as may be, than to follow a highway. The saving in cost of construction will usually be more than enough to pay for the right-of-way, and on such a route there need be no interference from trees, while many inconvenient angles and much trouble in guying and bracing are avoided. Shorter and stouter poles may also be used; in itself a very important consideration.

3. In electric line-construction it is preferable to dispense with cross-arms unless there are more than six wires. The best arrangement is to place one wire on a top-pin and the others alternately on the front and back of the pole, at a vertical distance apart of 12 inches. This construction not only costs less than properly braced cross-arms, but is much less conspicuous and therefore much less objectionable in a public street, is less interfered with by trees, and is far more durable. Much trouble is caused by the decay of cross-arms after they have been exposed a few years to the weather; they split at the ends so that the pins come out, and not infrequently break in two in the middle, thus fouling the wires.

4. In medium-sized towns and cities, especially in shaded streets, the incandescent lamp may be made to give a far better distribution of light for the same money than is possible with the "half-arc" so extensively used, and is much less troublesome to maintain in good working order. My own experience leads me to think that the lamps ought not to be of less than 24 or more than 32 candle-power. Use lamps of low rather than high efficiency, but run them at full candle-power, or even a trifle above. Good street-lights, well arranged, and renewed sufficiently often, are the best possible advertisement for any electric company.

5. Use large transformers as far as practicable, placing the consumers within 500 or 600 feet radius upon secondary mains. We

have used both two-wire and three wire mains. The latter plan is certainly to be recommended when the distance approximates or exceeds 500 feet, but for short distances, as for example when distributing within a single block at a pressure of 100 volts or more, it is a question whether the gain in cost of copper over the two-wire plan is of sufficient importance to offset the additional complexity.

6. It was found that raising the voltage in the residence district from 1,000 : 50 to 2,000 : 100 greatly improved the uniformity of distribution by lessening the potential drop without entailing any corresponding disadvantages. It would seem to be preferable, on every account, to use the higher pressure.

7. One of the most important minor points in the management of a plant is apt to be too much neglected; the maintenance of the insulation of the wires by promptly replacing all cracked and broken insulators, and by keeping the wires absolutely free from contact with uninsulated objects. The covered wires which lead into the hoods of the street-lamps need to be carefully looked after.

8. Number all the poles with yellow paint applied with a stencil on a black ground; and keep a record book of the position of each one and its distance by the line from the test-station.

9. In selecting a turbine-wheel, consult competent authorities as to the available fall and minimum quantity of water, and when making the purchase do not expect to get a thousand-dollar wheel for a hundred dollars. Pay a fair price and insist, not only that the wheel shall be well made in every way, but that it shall be tested by an expert before acceptance. If it does not give an average efficiency of 76 per cent. between half-gate and full-gate, it is not advisable to accept it, inasmuch as you can easily do better, as our own experience proves.

10. I think our experience shows that it is possible to largely increase the net earnings of an old plant without necessarily renewing it throughout, but plenty of time should be taken for consideration as well as for execution, in order to secure satisfactory results with a moderate expenditure.

Discussion.

Dr. Emery:—Although we are waiting for something of general interest I do not think that this paper should be passed without a word or two. The subject of the reconstruction of non-paying electric plants along modern lines is becoming of in-

creasing importance, and I have studied this paper with a great deal of interest. It is an example of a typical engineering paper. The various steps taken are enumerated, and the reasons for each step, and the author has gone somewhat outside of what may be strictly called electrical engineering, taken up problems from the standpoint of a civil engineer and given reasons based on the same considerations as those used in that branch of engineering. The paper will repay careful perusal by all who may have similar problems to undertake. The basis assumed, viz, that the maximum power which can be relied upon depends upon the minimum rainfall and proportional stream flow, is the correct one and is only varied where there are large reservoirs so regulated as to store water during freshets, and supply it in times of drought. There is only one drawback in the discussion of the water question which has not been mentioned. The ice frequently causes trouble, in Northern climates particularly, and at a season of the year when light is most desirable, so that the length and location of the head races, together with all available data as to ice gorges in the river, should be well considered before making a change of this particular kind.

[An illustrated description of the Niagara Falls plant was then given by Dr. Coleman Sellers and Mr. Lewis B. Stillwell.]

Twelfth Annual Meeting.—Morning Session.

Niagara Falls, N. Y., June 28, 1895.

President Duncan called the meeting to order at 10.30 A. M.

The President:—As it was impossible yesterday to discuss Dr. Emery's paper on "Alternating Current Curves," it has been thought best to open the proceedings this morning with a discussion of that paper. I will ask Dr. Pupin to open the discussion.

Dr. M. I. Pupin:—I intended to indulge in a brief comment on Dr. Emery's paper but a short conversation with Mr. Steinmetz convinced me that he had gone into the subject of the paper so thoroughly and exhaustively that it will be best for me to leave the whole discussion to him. There is one point only that I will mention, and that is, that I really do not see why Dr. Emery calls this a paper on alternating current curves. As I understand the meaning of the term, alternating current curves are those that are obtained experimentally from alternating current machines. The only reason that I can see for Dr. Emery's calling these curves alternating current curves, is because they resemble certain experimental alternating current curves, and evidently the object of the paper is to show how we can represent a certain class of alternating current curves approximately by means of an algebraical equation. I must object to what appears to me to be a favorite method of mechanical engineers. They are accustomed to represent some of their important physical facts by means of empirical formula, and they are satisfied if their formula represent facts with an approximate degree of accuracy. In electrical engineering we have no necessity for empirical formula, at any rate, not in this case, and it is not a step forward, but a step backward to substitute an empirical formula in place of an exact formula. After all, in theoretical and in practical electrical engineering we are not troubled very much by difficulties concerning the integration of functions which in any particular case represent the waves of current, etc. A difficulty that we meet is to construct an instrument that will perform our integrations, as for instance, the wattmeter. I do not see that Dr. Emery's paper has suggested any way of overcoming these difficulties. These difficulties exist now just as much as they existed before Dr. Emery wrote his paper, as for instance the difficulty of making a wattmeter give correct readings when both the alternating E. M. F. and the current, or any one of the two do not follow the simple sine law. But as we all know, this difficulty appears only at small loads. When the secondary load increases, then in most cases both the E. M. F. curve and the current curve conform very nearly to the simple sine law, and our wattmeter gives correct readings.

Mr. Steinmetz:—When first reading, and now hearing this paper on alternating current waves, I must confess I have not been

impressed very favorably with the desirability of introducing an empirical formula to represent these waves. It is true, in mechanical engineering, and sometimes even in electrical engineering, we are obliged to use empirical formula occasionally, wherever a rational equation is not available or is not known. However, I cannot see any reason for attempting to represent by empirical formula, phenomena of which a rational equation is in evidence, as is the case with alternating current and alternating E. M. F. waves. For these a rational formula exists: Fourier's series. All these alternating waves, no matter what shape and form they have, have one common feature, that is, they are

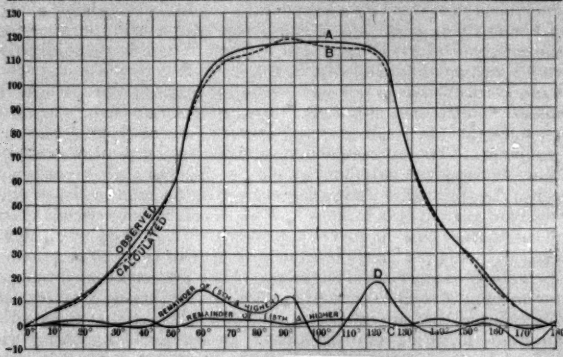

FIG. 1.—Analysis of Alternator Waves

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_i \sin i\varphi + y_i \cos i\varphi) \quad [i = 2n - 1]$$

Monocyclic Machine A.M. 12—150—600. Main coil. At no load.

Sine components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} x_i \sin iy$		Cos. components of wave $f''(\varphi) = \sum_{i=0}^{i=\infty} y_i \cos ix$	
x_1	= 104	y_1	= − 3.86
x_3	= − 24.5	y_3	= 4.33
x_5	= − 4.8	y_5	= .79
x_7	= 6.9	y_7	= − 1.48
x_9	= − 2.62	y_9	= 1.
x_{11}	= − 1.78	y_{11}	= .63
x_{13}	= 2.75	y_{13}	= − 1.21

$$e = f(\varphi) = 104.2\{\sin(\varphi - 1°\,10') - .242\sin(3\varphi - 9°\,55') - .046\sin(5\varphi - 8°\,35') + .068\sin(7\varphi - 11°\,42') - .027\sin(9\varphi - 20°\,50') - .018\sin(11\varphi - 19°\,50') + .29\sin(13\varphi - 23°\,50')\}$$

univalent functions of time, or in other words, for every value of time, one value only of the function exists. This is self-evident. But as a mathematical conclusion from this feature we derive that all these waves can be expressed by an infinite series of sine functions, and a rapidly convergent series, which with alternating machine currents consists of odd terms only, so that all these variously shaped curves can be expressed by very few terms of sine functions.

This equation is in evidence, and is very convenient, since in the integration of products of such series, all the terms vanish except the products of harmonics of equal order, so that the quadrature integral of such a series is nothing but the series of quadrature integrals of the individual terms.

Under these circumstances I do not see any reason for the introduction of the empirical formula in place of the rational equation.

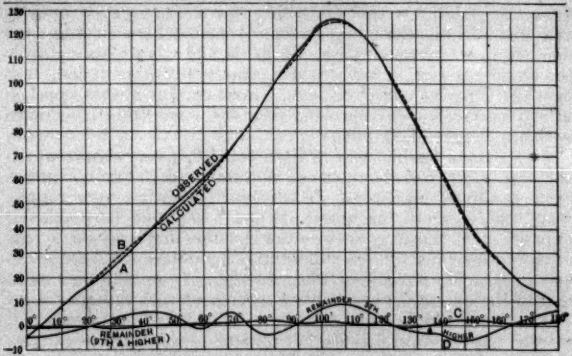

FIG. 2.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_i \sin i\varphi + y_i \cos i\varphi) \quad [i = 2n - 1]$$

Monocyclic Machine A.M. 12—150—600. 1,0 0 volts. Main coil. At 100 amp. load.

Sine components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} x_i \sin i y$	Cos. components of wave $f''(\varphi) = \sum_{i=0}^{i=\infty} y_i \cos i x$
$x_1 = 8$	$y_1 = -15.4$
$x_3 = -12.4$	$y_3 = 15.6$
$x_5 = -1.08$	$y_5 = -5.93$
$x_7 = -.232$	$y_7 = .70$

$$e = f(\varphi) = 99.21 \{ \sin (\varphi - 8° 58') - .20 \sin (3\varphi - 51° 40') - .061 \sin (5\varphi + 79° 41') - .0074 \sin (7\varphi - 71° 50') \}$$

However, even if we attempt to represent these curves by an empirical formula, I believe the exponential function proposed here is very unsuitable, for the reason that all the more common alternating waves contain numerous inflection points and extreme points. The exponential function, however, does not contain any inflection point or extreme point. Therefore in analyzing an alternating wave, wherever we meet any inflection point, or extreme point, we have to drop the previous exponential function and introduce a new function. This means that every half wave has frequently to be represented by as many as 8 or 12 or even more different empirical functions. This introduces a complication in the handling of these functions with which the complexity of Fourier's series is nothing, even if we go as high as the 19th harmonic or so.

When looking over the curves given as instances in the paper, I must confess that outside of the sine wave I have not found any figure resembling a real alternating wave, that is, such a wave as is given by an alternating current dynamo where electric conductors revolve through magnetic fields, and when glancing over the numerous E. M. F. waves which came to my observation, and of which I have a collection here, I must confess that it appears utterly impossible to represent them by exponential functions with any degree of simplicity.

I have here, for instance, in Figs. 1 and 2, a very simple wave, the E. M. F. wave of the main coil of a standard 150 K. W. monocyclic generator at no load and at load. This is a very simple wave, that is, contains a quintuple and a septuple harmonic of opposite sign. Looking back to the equation derived from a test of such a machine you see a quintuple harmonic of 23 per cent. and a septuple harmonic of 13.4 per cent., of opposite sign with that of the quintuple, in complete agreement with theory.

Thus these higher harmonics and Fourier's theory are not merely mathematical fictions, but rational representations of phenomena taking place in the machines.

DR. EMERY:—I feel very much gratified with the kindly way this paper has been received. I cannot, however, accept the indictment that I have presented empirical formula except in the same sense that that of the sine curve is an empirical formula. All are representative curves. My formula take in what is practically a sine curve as a special case, together with a large number of other curves. The formula are therefore in a sense more general than the sine function, though due credit has been given to the latter for the facility with which general investigations can be conducted when conditions not always practical are assumed. The curves given by electric generators are rarely sine curves. One may show an approximate sine curve which can without serious error be represented by and treated as a sine curve, but my system includes approximate sine curves and a large number of other curves which represent actual curves as

accurately as the sine curve does those of a particular form. In the investigation of principles we must put in place of the thing we have not, something which represents it approximately, whether it be by the development of a sine function or any other. I have made an attempt to develop an equation which, with different exponents, will represent a number of curves of practically typical forms, including the sine form, instead of being confined to the latter, and I have thought the investigation of sufficient importance to bring it here for the study of others. I have progressed further than I have attempted to present, but, regular business pressing, I became very much fatigued, and thought it better to put in shape what I had already developed, in the hope that it would interest and perhaps be extended by others. I believe that the method of investigation by means of actual momentary values will meet with increasing favor, and as the momentary values of E. M. F. and current must be multiplied together to give the momentary watts, I have endeavored for this purpose to produce simple equations that would apply closely to actual curves of different shapes. It is true that by assuming the sine function, direct values of the watts may be easily obtained for a given phase, and even approximate watts obtained for other curves, by considering equivalent sine curves and equivalent differences of phase, but after all the whole system is an artificial one. From the impressed E. M. F. two geometrically equivalent E. M. F.'s are assumed which is a well-known device to obtain certain solutions. For sine curves, mere power relations are accurately obtained in this way. The intermediate phenomena which actually produce the results are, however, smothered and concealed. The method of momentary values works out exactly as for direct current, and every operation can be traced. The equations given are only tools furnished to assist in the prosecution of a higher order of investigation. If in a given case the experimental curve of a given generator under particular conditions can be represented by one equation, by equating also the condition which causes a change, such condition may be imposed upon the first equation, thereby modifying the form of curve so that it corresponds practically with the experimental curve under the changed condition. The resulting momentary values have as before the same relations as in direct current work This field of investigation will be found fascinating and instructive, and my first object has been accomplished by the introduction of the subject to others.

MR. STEINMETZ:—I cannot quite agree with Dr. Emery that alternating machines do not give sine waves. Amongst other waves I have here in Figs. 7 and 8 the E. M. F. wave of a 300-K. W. three-phase generator, at no load and at load, which wave is practically a perfect sine, that is, the deviation of this wave from a true sine is within 2 per cent. or within the errors of observation.[1]

1. This machine is the same of which the field characteristic is given as Fig. 14 in my paper on "Some Features of Alternating Current Systems."

However, even where a wave is not a sine wave, but contains higher harmonics, it must not be thought that the separation of the total wave into the fundamental and the higher harmonics as done by Fourier's theory is merely a mathematical fiction. It is not fictitious but rational, and these higher harmonics have a real existence and find their origin in the machine in a way which can be accounted for by the shape of the magnetic and electrical circuit of the machine, and even predetermined by calculation.

Some months ago a friend of mine, Mr. E. J. Berg, made a mathematical investigation on the origin of these higher harmonics, which he intended to bring as a paper before the INSTITUTE for this meeting, but did not quite finish in time. He arrived at some very interesting results on the origin of these higher harmonics.

If the reluctance of the magnetic field of the alternator is uniform in all directions, the E. M. F. wave is very closely a sine wave. However, as soon as variations of magnetic reluctance take place, as by the passage of armature slots across the field poles, higher harmonics are introduced. Thus, if the armature contains k slots per pole, the magnetic reluctance will rise and fall k times per half wave, that is, will fluctuate with the frequency $2\,k\,N$, where N is the frequency of the alternator, and thus if we denote by M the average magnetic flux issuing from the field pole, then the instantaneous flux will be denoted by

$$m_0 = M\,(1 + \varepsilon \cos\,(2\,k\,\varphi - \tilde{\omega}))$$

where $\varepsilon\,M$ is the amplitude of the magnetic variation, $\tilde{\omega}$ its phase angle, and the instantaneous magnetic flux interlinked with the armature conductors will be denoted by

$$m = M \sin\,\varphi\,(1 + \varepsilon \cos\,(2\,k\,\varphi - \tilde{\omega}\,)).$$

Differentiating this, we get as the equation of E. M. F.:

$$e = A\,\left\{\cos\,\varphi + \frac{2\,k+1}{2}\,\varepsilon \cos\,[(2\,k+1)\,\varphi - \tilde{\omega}]\right.$$
$$\left. - \frac{2\,k-1}{2}\,\varepsilon \cos\,[(2\,k-1)\,\varphi - \tilde{\omega}]\right\}.$$

As you see the E. M. F. wave contains two sine waves due to the variation of magnetic reluctance.

If $k = 1$, as in a uni-tooth alternator like the monocyclic machine mentioned above, this equation gives:

$$e = a \sin\,(\varphi - \tilde{\omega}_1) + b \sin\,(3\,\varphi - \tilde{\omega}_3).$$

That means, you get a fundamental and a triple harmonic, but no higher harmonics. This agrees with the test.

If $k = 3$, as in a uni-tooth three-phaser, the E. M. F. equation becomes:

$$e = a \sin\,(\varphi - \tilde{\omega}_1) - b \sin\,(5\,\varphi - \tilde{\omega}_5) + c\,(7\,\varphi - \tilde{\omega}_7).$$

It only contains a fundamental and a triple harmonic. The latter being 24 per cent. of the fundamental at no load and 20 per cent. at load. All the higher harmonics are very small and practically negligible. The exact equation of the wave is:

No load: $\sin \varphi_1 - .242 \sin (3\varphi - 6.3) - .046 \sin (5\varphi - 2.6) + .068 \sin (7\varphi - 3.3) - .027 \sin (9\varphi - 10.0) - .018 \sin (11\varphi - 6.6) + .029 \sin (13\varphi - 8.2)$,

100 amperes load: $\sin \varphi - .20 \sin (3\varphi - 24.6) - .061 \sin (5\varphi + 124.7) - .007 \sin (7\varphi - 8.8)$;

but it can with sufficient exactness be expressed by the first two terms only:

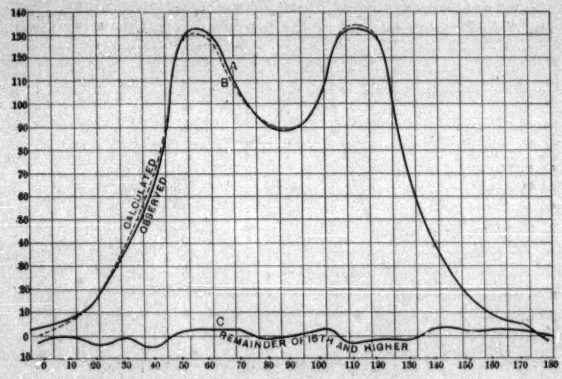

FIG. 8.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_i \sin i\varphi + y_i \cos i\varphi) \quad [i = 2n - 1]$$

Uni-tooth Threephase Machine A.T. — 12 — 150 — 600

Y. E. M. F. at no load.

Sine components of wave $f(\varphi) = \sum_{i=0}^{i=\infty} x_i \sin i x$		Cos. components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} y_i \cos i x$	
$x_1 =$	109.5	$y_1 =$	10.5
$x_3 =$	— 12 8	$y_3 =$	— 3.25
$x_5 =$	— 22.8	$y_5 =$	—.10.6
$x_7 =$	— 12.4	$y_7 =$	7.87
$x_9 =$	— 0.55	$y_9 =$	.245
$x_{11} =$	— 2.95	$y_{11} =$	— 4.2
$x_{13} =$	.595	$y_{13} =$	3.38

No load: $\sin \varphi - .242 \sin (3 \varphi - 6.3)$,

100 amperes load: $\sin \varphi - .20 \sin (3 \varphi - 24.6)$.

Representing this curve by exponential functions, we would require for every half wave four different functions, and you can imagine how difficult it would become by using four different functions for various lengths of the same half wave, how difficult to handle these formulas, infinitely more difficult than to use two sine functions.

The matter becomes still worse when you take, for instance, the wave of the standard 150 K. W. three-phase generator of which Figs. 3 and 4 give the E. M. F. wave per circuit, that is between collector ring and common connection, Figs. 5 and 6 the E. M. F. wave between lines. Figs. 3 and 5 correspond to no load, Figs. 4 and 6 to 25 amperes load of the machine, at 2,000 volts. These

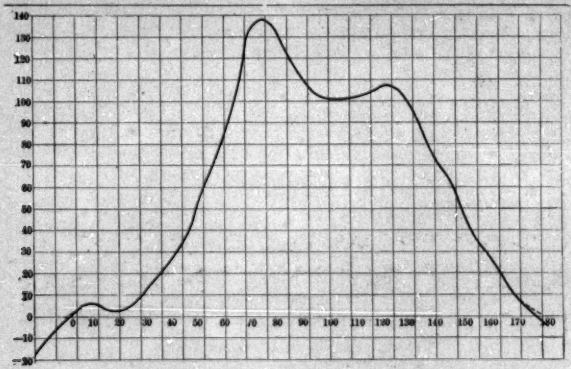

FIG. 4.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_i \sin i\,\varphi + y_i \cos i\,\varphi) \quad [i = 2n - 1]$$

Unitooth Threephase Machine A.T. — 12 — 150 —600.
2,000 volts. Y. E. M. F. at 25 amp. load.

Sine components of wave $f(\varphi) = \sum_{i=0}^{i=\infty} x_i \sin i\,x$	Cos. components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} y_i \cos i\,x$
$x_1 = +\ 106$	$y_1 = -\ 13.9$
$x_3 = -\ 19$	$y_3 = +\ 3.6$
$x_5 = -\ 3$	$y_5 = +\ 8.8$
$x_7 = +\ 2.3$	$y_7 = -\ 1.1$
$x_9 = -\ 1.9$	$y_9 = +\ 1.0$
$x_{15} = -\ 2.1$	$y_{15} = -\ .7$

waves contain numerous inflection points and would require eight respectively twelve applications of different exponential functions. That is a complexity which it would be useless to attempt to untangle. Expressed in Fourier's series, however, the wave contains a moderate sized triple harmonic, a strong quintuple, and a moderate sized septuple harmonic, while all the higher harmonics are negligible.

The waves in Figs. 3 and 4 can be expressed by four terms only, namely:

No load: $\sin \varphi - .12 \sin (3 \varphi - 2.3) - .23 \sin (5 \varphi - 1.5) + .134 \sin (7 \varphi - 6.2)$,

25 amperes load: $\sin \varphi - .176 \sin (3 \varphi + 11.7) - .085 \sin (5 \varphi - 33.8) + .01 \sin (7 \varphi + 26\ 6)$.

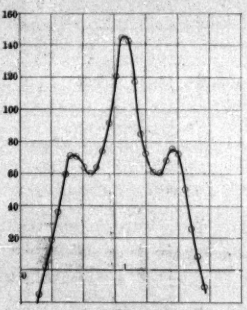

FIG. 5.

No load.

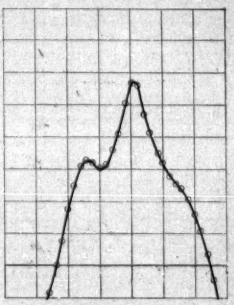

FIG. 6.

25 amp. load at 2,000 volts.

Potential waves A.T. 12 — 150 — 600.

Their complete expression is:

No load: $\sin \varphi - .12 \sin (3 \varphi - 2.3) - .23 \sin. (5 \varphi - 1.5) + .134 \sin (7 \varphi - 6.2) - .002 \sin (9 \varphi + 27.7) - .046 \sin (11 \varphi - 5.5) + .031 \sin (13 \varphi - 61.5)$,

25 amperes load: $\sin \varphi - .176 \sin (3 \varphi + 11.7) - .085 \sin (5 \varphi - 33.8) + .010 \sin (7 \varphi + 26.6 - .009 \sin (9 \varphi + 39.5) - .020 \sin (15 \varphi + 130.8)$.

The waves in Figs. 5 and 6 are the sum of two of the waves 3 and 4 displaced by 60°.

From all this you can easily see how utterly hopeless the attempt must be to express such waves by empirical exponential functions.

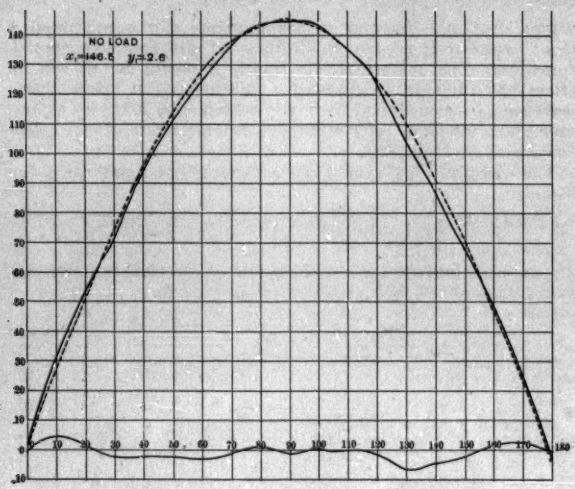

FIG. 7.

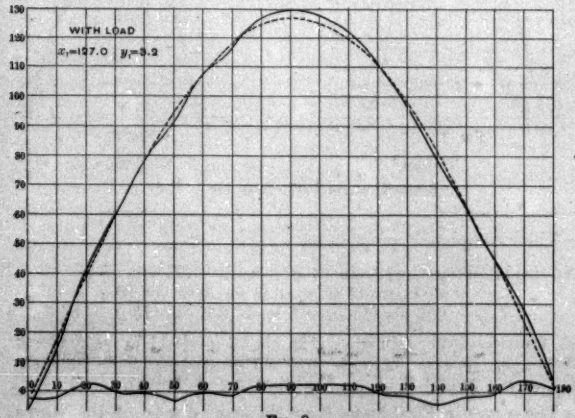

FIG. 8.

Analysis of Alternator Waves.
Polytooth Threephase Machine A.P. 12 — 300 — 600.
3 slots per pole and phase. E. M. F. at no load and load.

DR. EMERY :—We are to be congratulated that this discussion has induced Mr. Steinmetz to show a number of interesting curves from novel machinery recently developed, and the adaptation of the Fourier series to the same. For present purposes, however, it should he noted that the same results would have been obtained by somewhat similar combinations of other than sine curves. The painter, to produce his effects, puts a particular color over a particular area, another color over another area, and so on until a representation of the desired object is secured with sufficient accuracy for the purpose. Any curve can be represented and formulated by similarly applying at proper intervals representing time, a sufficient number of known curves of proper sign and amplitude, and the equation of the original distorted curve will be the sûm of the equations of the regular curves. It is not necessary to be confined to a sine function. Any function can be employed which will represent the conditions that cause the particular distortion. If, as Mr. Berg and Mr. Steinmetz appear to show, the changes in reluctance due to toothed construction indicate the selection of a particular harmonic, they would also show the manner in which any other curve should be applied. We only claim that it is much more rational to find the elements of the applied curve from the conditions instead of assuming a sine curve, and this is what is meant in the paper (§ 66) by "imposing upon the original function another function based on the actual conditions which produce a certain change." The general method is the same in each case. The whole is built up from various parts. The particular equations used in this first presentation of the method are especially valuable, for the reason that they represent so many different forms of curves by a simple change of the exponent, but the very act of imposing conditions mathematically on such curves would immediately change their shapes. If the experimental curve had points of inflection the representative curve would also have the same. The mere application of one curve upon another, so to speak, as the artist puts on his color, is mechanical, empirical, or whatever it may be called, *in either case*. The selection of the particular curves thus combined is certainly empirical if it be assumed in the first place that all are sine curves, and the operation can only be made rational by formulating the conditions which produce the change. The trajectory of a projectile could be represented by combining a series of sine curves by the Fourier method, but everybody knows that the underlying functions are not duplications of a sine curve, but a combination of simple functions which give as a resultant practically two parabolas combined to form an unsymmetrical curve.

The committee on resolutions then submitted the following report, which on motion was adopted.

To The American Institute of Electrical Engineers.

Gentlemen :—Your committee appointed to draft resolutions regarding the courtesies extended to its members during its Niagara Falls meeting, beg to submit the following preamble and resolutions as its report :

Whereas, the American Institute of Electrical Engineers at this its 98th regular and 12th general meeting assembled at Niagara Falls, June 25, 26, 27 and 28th, 1895, has received many courtesies and privileges from various interests identified with the City of Niagara Falls, and as the Institute has appointed the undersigned committee to voice the expression of the Institute's appreciation, it is hereby

Resolved, 1st, that the American Institute of Electrical Engineers feels a deep sense of gratitude for the courtesies extended to its members collectively and individually, and believes that the privileges thus bestowed have in no small degree contributed to the success of our meeting and the enjoyment of our members.

Resolved, 2nd, that the thanks of the Institute be and they are hereby extended to the Niagara Falls Power Co., the Cataract Construction Co., the Westinghouse Electric & Manufacturing Co., and their officers and employees, for their kindness in opening their unequalled power station and works, and to the General Electric Co. for opening their converting plant for utilizing power at the works of the Pittsburgh Reduction Co., for the inspection of the members and guests of the Institute, and for their full and cordial explanation of those most interesting plants.

Resolved, 3rd, that the thanks of the Institute be and they are hereby extended to the Niagara Falls Light and Power Co. and the Niagara Falls Paper Co. for the opportunity afforded for the inspection of these companies' plants.

Resolved, 4th, that the thanks of the Institute be and they are hereby extended to the American Telephone and Telegraph Co., for the generous offer of the free use of its long distance lines to all parts of the United States, and to Capt. Brinker for opening the Falls Observation Tower to members and guests of the Institute.

Respectfully submitted,

B. F. Thomas, Chairman,
B. J. Arnold,
W. J. Hammer,
Committee.

The Secretary announced that Mr. Brackenridge, one of the engineers of the Cataract Construction Company, had placed at the disposal of members of the Institute and guests a special train from the power-house through their model village (Echota) and over the grounds of the company, for three o'clock this afternoon.

A paper presented at the 12th General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 28th, 1895. President Duncan in the Chair.

EXISTING COMMERCIAL APPLICATIONS OF ELECTRICAL POWER FROM NIAGARA FALLS.

BY W. L. R. EMMET.

The first arrangements which were made by the Niagara Falls Power Company, for the commercial application of the electric power of Niagara Falls were with the Pittsburgh Reduction Company for the delivery of direct current for the manufacture of aluminium by their electrical process. In this process the cost of power is an important factor, and it is therefore naturally one of the first industries which we would expect to find attracted by the great advantage offered by this town. The contract made with this company requires the continuous delivery of 1500 electrical horse-power in direct current at 160 volts. The aluminium process is a continuous one, and cannot be interrupted without serious loss, since the product is not perfect while the furnaces are being started, or when they are not in their normal working condition. It is therefore necessary that spare apparatus be always held in reserve so that in case of accident the proper working conditions cannot be seriously interrupted. To fill these requirements the Cataract Construction Company has ordered from the General Electric Company the apparatus which is now installed in the Reduction Company's building.

This apparatus consists of four rotary converters, having capacity of 400 K.W. each, and 8 transformers, each with a capacity of 200 K. W. The rotary converters are intended to be used three at once in parallel, the fourth being always in reserve. These machines transform two-phase currents at 115 volts into direct current at 160 volts, the output of the three being 7,000 amperes which will be delivered continuously.

The stationary transformers are designed for a primary voltage of 1000 and a secondary voltage of 115, their function being to reduce the current generated in the main power station, to a suitable pressure for conversion into the desired direct current. In addition to the rotary converters and transformers, the General Electric Company has furnished switchboards, conductors, cooling apparatus, cables to connect the plant to the generating station and all the necessary accessories.

Rotary Converters.

The rotary converters installed, are of 20 poles, and are operated at 150 revolutions per minute, giving a frequency of 25 cycles per second. The armature is of the smooth body type, having a cylindrical winding of conductors formed of pressed stranded cables. These cables are made up of small bare copper wires loosely twisted into a strand. This strand is then placed in a die under a powerful press and is pressed into a rectangular form, the wires being so pressed together that the cable has practically the same effective copper section as a solid bar of the same size. In spite of this pressing together of the wires, we find, by experiments, that parasitic currents are practically eliminated by this form of construction. On each side of the laminations of the armature there are cylindrical extensions for the crossings of the armature conductors. The whole winding is on a cylindrical surface, the ends of the stranded cables themselves being jointed together at the outer edges of the extensions. This machine has a small armature reaction, 5,500 ampere-turns per pole, and has an average potential difference between commutator bars of 3.6 volts. Copper gauze brushes are used, there being 20 studs with three brush-holders per stud. The brushes are shifted and raised from the commutator all at once by hand-wheels. The field frame of the machine is cast-iron, and the magnet cores and pole-pieces are of cast-steel. The cores are made in spool form, there being an enlargement at one end to form the pole-pieces and at the other, to increase the area of contact with the cast-iron. The base is in a single casting with the pillow blocks, giving rigidity and alignment. The commercial efficiency of these machines is about 94 per cent. [See Fig. 1.]

The stationary transformers used in the plant are of 200 K.W capacity each, eight being used in all. They are kept from injurious heating, by currents of air delivered from below, which

passes upward through the body of the transformer, and over the surface of the coils. Both the laminations and the coils are built with spaces for the circulation of air, and the space pieces in the iron are so arranged that the air will follow the the paths where it will do most good. The transformers are placed in the room

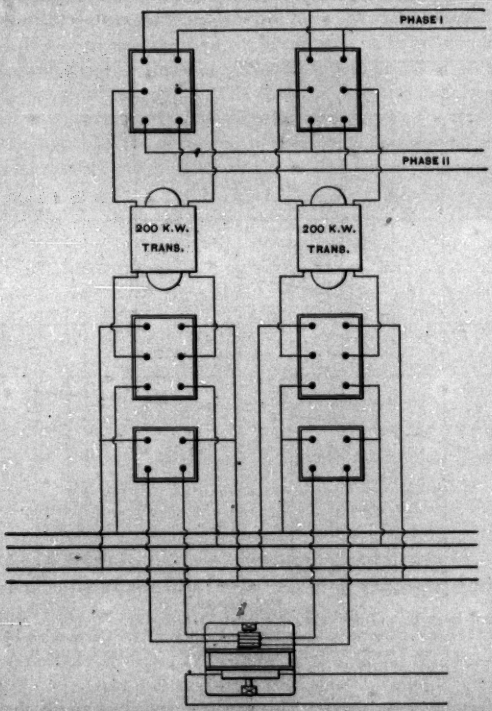

FIG. 1.—Distributing Switchboard Connections. Pittsburgh Reduction Co.

without casing or covering, so that much of the heat is carried away by radiation, and by convection of the outside air. The construction of these transformers, will be clearly understood when they are examined as they stand in the Pittsburgh Reduction Company's building. The laminations are held between

two cast-iron frames, by bolts and side frames, which hold the whole structure rigidly together. The weight of the laminations is borne by two pieces of "I" beam, held between the end frames, on which the edges of the punchings rest. These "I" beams also serve to form a compartment under the transformer into which the circulating air is delivered. There are four primary and five secondary coils in the transformer alternately placed with

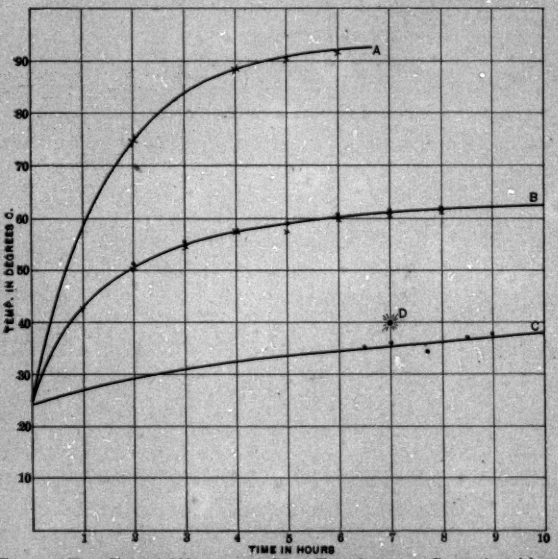

FIG. 2.—Heat Test of 200 K.W. Air-Blast Transformer. Curve A, without blast. Curve B, blast 1040 feet per minute. Curve C, air issuing from Transformer. Point D, laminations after 7 hours with Air-Blast at 1040 cu. ft. per minute.

air spaces between them. This arrangement gives ample cooling surface, and freedom from magnetic leakage. The accompanying curve shows the temperature of one of these transformers when run at full load, with an air-blast of 1,040 cubic feet per minute, requiring a power of about one-quarter of one per cent. of the transformer. The temperatures here given are taken by resistance measurement of the coils. It will be observed that the effect

of the air-blast is very great, the maximum temperature being practically reached in three hours. The curve also shows that if the air-blast was stopped when operating under normal conditions, about three hours would elapse before a dangerous temperature was reached. [See Fig. 2.]

The air for cooling transformers is conveyed to them through a large duct or covered trench above which they are placed. This space is formed by an excavation in the floor, with brick retaining walls, and is covered by iron plates flush with the floor, all being made practically air tight. The plates on which the transformers stand, are provided with openings in the form of grids with slide valves, by which the admission of air to the transformer can be regulated at will, or shut off altogether. The air is supplied by

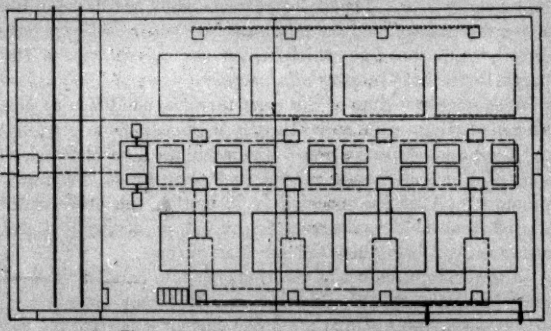

FIG. 3.—Floor plan, 48′ 4″ by 87′. Pittsburgh Reduction Co.

a 60-inch Sturtevant blower, directly coupled to a five-H.P. motor. Two of these are installed, one as a reserve. Either will give sufficient air to cool 3,000 H.P. in transformers.

The room in which this apparatus is placed is 48′x87′, and is designed and arranged to receive apparatus to the amount of 4,000 H.P. Only half this capacity is now installed. This plan was laid out with a view to the occupation of a minimum space, and, although the machines are large for their output, it fairly illustrates the compactness attainable in a plant of this character. Figure 3 is a floor plan of the room.

The system of conductors and switches in this plant is so arranged that every piece of apparatus is readily interchangeable with every other, so that the spare pieces are always ready in case

of trouble, no matter where the trouble may occur. This, as I have said, is made imperative by the nature of the reduction process in which a shut-down entails heavy loss. The arrangement of conductors and of apparatus is such as to require about the minimum amount of copper under the circumstances. The air spaces below the transformers contain all the conductors connecting the transformers together, and to the outside lines. The conductors from the switchboards on the alternating side of the machines lead downward into the air chamber, the conductors from these boards to the machines lead through open ducts covered by floor plates. On the direct current side of the machine an open passage is left under the floor, which serves as a means of getting at the lower brushes and also provides space for the cables and wiring. The direct current switchboards are placed above this passage, and the terminals from their backs are bolted directly to the 'bus bars which deliver the current to the Pittsburgh Reduction Company's furnaces.

With some machines of this class there is no difficulty whatever in starting, while with others it is impossible to start from the alternating current alone. The machines here installed, will start from the alternating current and come up to synchronism promptly. After one machine is in motion, the others will be started from the direct current side, a set of connections and a resistance box being installed for that purpose.

In throwing machines of this character into parallel, great care must be observed. We must be sure that they are exactly in synchronism, and also that the direct current polarity is the same. To accomplish this we have arranged a system of phase lamps, by which both these points are shown. Each machine is fitted with 7 lamps which are required for lighting the room and the machine. Four of these are on the collector side of the machine and are so arranged by switches that they can be connected as phase lamps, two on each side of the two phase system between the machine and the alternating 'bus bars. When all four lamps burn together and the fluctuations of the light become very low, the machine is ready to throw in. If through misplaced switches or wrong connections the polarity of the machine and alternating circuit do not agree, two of the phase lamps will burn while the others are out.

The General Electric Company has installed four 900,000 c. m. cables which connect this plant with the main generating station.

These cables are lead covered and insulated with rubber. They are jointed inside of the Reduction Company's building to small cables which lead to the switchboards near the transformers.

Another of the important contracts closed by the Niagara Falls Power Company for the delivering of electric power from the Falls, is that with the company which manufactures the substance which has been given the name "carborundum." This substance is carbide of silicon; it is of extreme hardness and is used as an abrasive in the same manner as corundum or emery.

This substance is manufactured from a mixture of sand and coke by the application of heat derived from an electric current. The ingredients are mixed together and piled in a furnace between two large carbon electrodes. A current is then passed through the mass which gradually heats. After a high temperature is attained the carbon and silicon begin to combine, and the

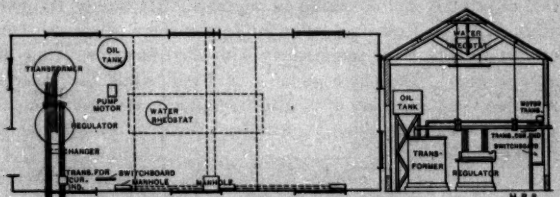

FIG. 4.—Arrangement of Apparatus. Carborundum Co.

product collects in crystals on the cooler external surface of the mass. After the process has gone on for about 24 hours, the current is stopped and the mass allowed to cool.

The carborundum crystals are found in a loose crust on the surface. This process presents rather a peculiar electrical problem, since as the furnace heats, the resistance diminishes, and since it is desired to supply a given amount of power continuously to this falling resistance, the amount of power to be delivered in the present case is to be 1,000 H. P. The pressure required at the beginning of the process is 250 volts, and at the end 100 volts. The current begins at 3,000 and ends at 7,500 amperes. The power is to be taken from one side of the 2,000-volt two-phase system.

A number of different methods of supplying this power were proposed and discussed, and the contract for building the appar

atus was finally awarded to the General Electric Company, the fitness of the design proposed being, I believe, the principal ground for awarding the contract. [See Fig. 4.]

The chief merits of this apparatus are, first, it works without change of connection or opening of the circuit. Second, it is practically non inductive at all stages of the process, the apparatus being so designed that the magnetizing currents are small, and self-induction is in no way depended upon for the control of the current. Third, the process is continuous, the voltage varying gradually, not in steps. Fourth, the apparatus is controlled automatically.

The apparatus consists in a transformer and a regulator. The former has a fixed ratio of transformation, being built for an E. M. F. of 2200 in the primary, and 185 in the secondary. The regulation is virtually a transformer in which the mutual induction of primary and secondary is variable. Its design is somewhat similar to that of an induction motor, there being two concentric parts built of laminations with distributed windings in slots on each. The outer member is fixed, while the inner is movable through an arc of 60°. This angle corresponds to the space between two poles, the windings being so grouped as to form six poles.

In addition to the regular windings, the movable member is fitted with closed turns of low resistance between the poles, so placed as to prevent magnetic short-circuiting when the regulator is in or near mid-position. Thus the regulator is a transformer in which the inductive relation of the two coils is reversible, and in which the mutual induction is variable

The connections of the transformer and regulator between the line and furnace are shown in Fig. 5. The regulator there appearing has, for the sake of simplicity, been shown with two poles only, and of Gramme construction, while six poles and cylindrical winding are in reality used.

The transformer and regulator will be connected together and to the furnace by heavy copper bars, suspended above them from the roof of the building. The winding on the stationary part of the regulator is placed in series with the transformer secondary, and that on the movable part is in shunt. The conductors at different points are proportioned to the currents which they carry. Eight bars, $4'' \times \frac{1}{4}''$ of suitable lengths, give the desired arrangement.

At the beginning of the process the resistance of the furnace is at its maximum, the current from the transformer divides, part energizing the movable part of the regulator, the remainder passing through the stationary part of the regulator, the effective E. M. F. being thereby raised from 185 volts to 250 volts.

From this position the regulator is gradually turned as the resistance falls, the result being that the added E. M. F. and the amount of current withdrawn from the circuit by the shunt portion of the regulator both continuously diminish. When the regulator reaches mid-position, the two parts have no mutual induction, and the regulator is entirely neutral except that the magnetizing current and losses of its two parts are supplied at the expense of the transformer.

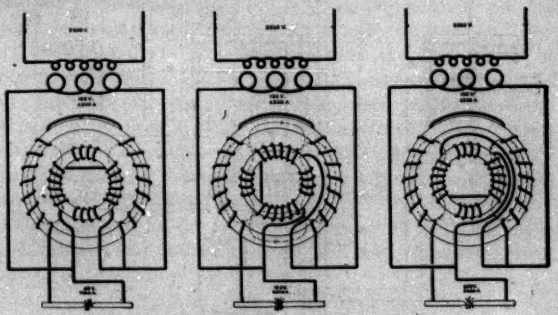

FIG. 5.—Feeder Regulator. Carborundum Co.
Secondary 85v 7500A. Secondary 65v 3000A.
Primary 185v 3000A. Primary 185v 150 A.

As the regulator passes from the mid-position, the resistance of furnace continuing to fall, the E. M. F. generated in the stationary part begins to oppose the E. M. F. of the transformer, and the current in the furnace rises, being now the same as the currents from the transformer, and from the movable part of the regulator.

The regulator is so arranged that it can be turned either by hand or by a motor. In the carborundum furnace the variations of resistance are so irregular that a continuous angular motion of the regulator can not be used. If the variation of resistance was uniform throughout the process, the regulator could be slowly turned by a properly guarded constant speed motor and would be automatic.

The transformer and regulator are cooled by circulating oil. A pump and two tanks are used, one above the other. The upper tank contains a coil of pipe in which water circulates. It is so arranged that the moving oil must flow over this coil and give up its heat. The lower tank receives the oil from the apparatus, and prevents an overflow in case the pump stops.

In the transformer, the oil is admitted at the bottom, and flows upward through and around the coils, the coils being placed vertically and the laminations horizontally. After overflowing at the top of the coil space, it finds its way downward over the outer

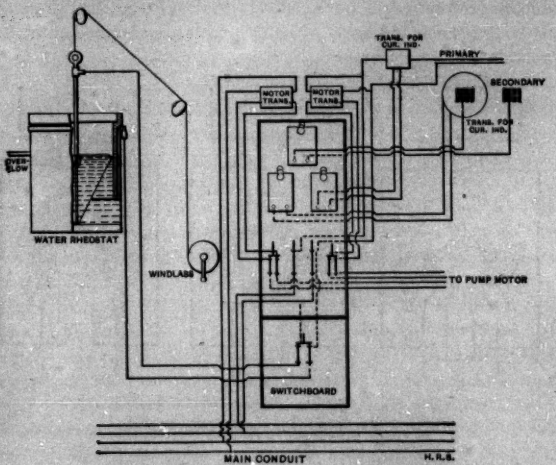

FIG. 6.—Distributing Switchboard. Carborundum Co.

surface of the laminations. The regulator is so constructed that it revolves in a horizontal plane. The cooling oil flows upward through the air-gap between the two parts, and down over the outer surface of the stationary part, and inner surface of the movable part. The transformer is placed in a cylindrical tank, while the regulator is self-contained, the cast-iron supporting shell forming the outer casing.

The oil is lifted by a small induction motor geared to a pump. Since the process is not continuous, some means of opening the circuits must be provided so that the apparatus may be cut out

when the process is complete. The arrangements which have been made for this purpose are shown in Fig. 6. A pair of large snap switches is placed, one in each lead from the generating station. In parallel with one of these switches a specially designed water rheostat is placed. This rheostat consists of an iron tank lined by a section of vitrified pipe of large diameter.

This tank is about half filled with water, and a pointed electrode is so arranged that it can be raised or lowered from the water by a rope leading to a small winch. Before the switch is opened, the electrode is lowered into the water, which provides a non-inductive circuit in parallel with the switch. After it is opened the electrode is raised, which increases the resistance till the circuit is broken at the surface of the water. The vitrified pipe prevents the possibility of arcing or contact between the electrode and the iron tank.

A switchboard will be installed on which the switches will be mounted, also the switches for controlling the pump motor. Current indicators will be mounted on this board which show the current in the primary leads, also the current passing to the furnaces. These indicators will be operated from small transformers which encircle the conductors. A voltmeter will also be installed which will show the E.M.F. at the furnace terminals.

This plant will for the present be operated by cables branching from those leading to the Pittsburgh Reduction Company's plant.

Discussion.

Mr. Jules Neher:—We have all had an opportunity of visiting the transformer house of the Pittsburgh Reduction Company, and certainly we all have admired the beautiful workmanship and the imposing size of the apparatus described. I am peculiarly interested in these machines, and therefore would like to be permitted to put a few questions to the parties who were connected with their construction, in the hope of receiving a few pointers. I know by actual experience that a revolving converter can be rated at about 130 per cent. of a generator of the same dimensions, owing to the fact that a part of the current goes directly from the collector ring to the commutator without in fact making use of the armature winding or the boosting effect of the armature winding.

The machine to act as a revolving converter is a synchronous motor, and as I also know by experience, the synchronous motor works better in synchronism if there is a certain flywheel effect to it. I think it is cheaper to make a smaller flywheel running at a high speed than to make a large flywheel running at very slow

speed. This is the second point. Another point: In a machine where we have very many poles, the sensitive part of the commutator is very much smaller naturally, or extends over a very much smaller angle than on the machine with a few poles, where the neutral point extends over an angle of quite a number of degrees. This naturally has been overcome by the use of very many comtator bars, as is done on the Siemens-Halske machines; but on a machine for reducing purposes where the load varies very much, and often varies suddenly, it seems to me that the sensitiveness of the commutator is a very important point. I would therefore like to know just why the number of poles, or why the machine in this respect was planned so large. In looking at the 5,000 H. P. generators running at a speed of 250 revolutions with a 12-pole field, it naturally is striking, why a secondary machine which has no strains on the shaft, which, in fact, is only a revolving flywheel, should have the exceedingly slow speed of 150 revolutions and a 20-pole field. I have compared these revolving transformers with the one in the power-house back of the switchboard structure, which is to be used as an exciting machine for the generators. Now this small machine has a capacity of 200 K. W., and runs at a speed of 500 revolutions, while the Pittsburgh Reduction Company's transformers have a capacity of 375 K. W. and are about ten times as large. I also have compared these machines with the direct current generators, of say 1,000 H. P., running at the Corliss engine speed, or about 80 revolutions. Now I have seen machines of this type which are about the same size and weight as the Pittsburgh Reduction converters, but with double output and about half the weight, which would make these machines practically four times smaller. I would be very happy if I could get an idea why these large dimensions were chosen, not only on account of the slow speed, but even compared with other slow speed machines, which, as I just stated, are about one-quarter the weight.

MR. EMMET:—The building of direct current dynamos is something which is considered by a great many people a very simple matter as compared with some of the other problems in electrical work. It, however, is a fact, that the design of the direct current machine is a matter of more complexity than anything else that we have in electrical science. For certain kinds of machines, at certain speeds, and certain outputs and certain voltages, the problem is very simple and a good result is certain. Under other conditions a good result is extremely difficult to obtain. This is particularly true of large machines. A very considerable proportion of the large direct current machines which have been built have been failures to a greater or less extent, and this has been particularly true in machines which were operated with copper brushes at low potentials. With rotary converters we have several additional conditions which still further complicate the problem. Even now there are very few rotary converters in opera-

tion so that we have not much knowledge founded on experience. The machines in question were built, or designed, nearly two years ago. We have had them complete in our shops very nearly a year. I think there was on the part of the designing engineers, who are not here to speak for themselves, some misapprehension as to the uses to which these machines were to be put. A rotary converter can operate in many ways. It can fill many functions. It can compound for losses in the line, and it can operate with considerable variation of secondary E. M. F.

It is my belief that our engineers, knowing that the machines were being designed for an electrolytic process, were apprehensive as to the effect of sudden fluctuations of load on the maintenance of constant potential. The specifications on which this contract was closed, recited at very great length what the machines should do. The specifications were prepared by the engineers who designed the machines, some time before the contracts were closed, and they were possibly based on a slightly wrong impression as to what the machine should do. We were anxious to live up to those specifications exactly, and the result was the machinery as it stands.

The efficiencies warranted in these specifications were so high that copper brushes were a necessity. The loss with carbon at such low potentials is considerable. The present machines requiring something in the neighborhood of 80 or 100 square inches of carbon surface to take off the current, the heating effect of this on the commutator would be great. A copper brush being decided on, it was thought desirable to make a very low armature reaction in the machine, and to get a low armature reaction with the necessarily low voltage per bar, a large number of poles was indispensable. So by the operation of a system of reasoning which I cannot fully explain at present, but which in the mind of the designer was undoubtedly sufficient, the present form of machine was adopted. It is a large machine for the output, simply because its speed is low.

Since these machines were built, we have designed other rotary converters for the purpose of making propositions on similar work. Of these, some have been copper brush and some carbon brush machines; but they all have been smaller than the ones under consideration now. We have also built several three-phase rotary converters of the same output as these machines which are now in operation and giving excellent results.

The exact ratio between the output of a machine as a rotary converter, and as a direct current generator, cannot be stated definitely. It is one that must depend very much upon circumstances and what the rotary converter is to do.

MR. NEHER:—I am, indeed, thankful for the information obtained from Mr. Emmet. I did not touch at all upon the point of the copper brushes, although I think, as Mr. Emmet has explained to us, this was one of the leading points which determined the size and the number of poles in that machine. As to the use

of common copper brushes in general for electrolytic machines, I can say that I have seen a good deal of it. I think I have seen the largest electrolytic machines that are in operation, that is at the aluminium works at Neuhausen, Switzerland, where there are machines directly connected to turbines, vertically, which deliver 7,500 amperes at 60 or 70 volts. These machines have 24 sets of copper brushes, and it requires the attendance of a man at each machine continuously, to attend to those. It was found impossible there to use carbon brushes on account of the enormous length of the commutator which would have been necessary; though since then, I have seen the same difficulty overcome in the present machines of the Pittsburgh Reduction Company, and in fact on two old machines, vertical bipolar machines, which had been operated with copper brushes, and very heavy copper brushes, about three-quarters inch thick, and where the copper was ground off at the rate, I think, of between $100 and $200 worth per month. There the copper brushes were replaced by carbon brushes, and, interesting to say, by carbon brushes which stood lengthwise with the direction of rotation covering the commutator over a space of about 2½ inches. I saw these machines operate after that, beautifully and without any loss at all. The commutator stood for years and the expense in brushes was nominal.

As to the design of these large converters with carbon brushes, I do not think it would have been impossible, though naturally the whole arrangement of the machine would have become entirely different. As much as I have seen of large generators with copper brushes in the various Edison electric light stations, and of Siemens' make, the machines most assuredly can work perfectly with copper brushes, and I believe that the rotary converters in this station will work perfectly well.

Mr. Steinmetz:—When comparing these large converters revolving at a very low speed at the Pittsburgh Reduction Company's works, with the small rotary converter running at very high speed as exciter in the power-house, it is quite remarkable how much larger for their output the former machines are. However, the reason for the design adopted in these machines lay in the particular nature of the work required from them, in which it is of the utmost importance that the machines shall never shut down, but run continuously for months and months. For this reason it was considered advisable to use the utmost conservatism in their design. If instead of using an average difference of potential of 3½ volts per commutator bar, it had been deemed safe to operate them at 15 volts average potential between commutator bars, and carry 2,500 amperes off by carbon brushes, it is obvious that a smaller number of poles and thus a smaller machine might have been used. However, this was not considered desirable, but we rather preferred to put more material in the machines and be perfectly safe.

Besides, another point has to be taken into consideration.

Polyphase continuous current machines can fulfil either the function only of converters from alternating to continuous current, or can operate not only for conversion from alternating to continuous current, but also to control the potential.

If a machine is intended only to receive the alternating current at whatever voltage it may be impressed upon it, convert it into continuous current and supply continuous current at whatever voltage corresponds to the alternating current voltage which happens to be impressed upon the machine, then the machine can be much smaller than a continuous current dynamo of the same output, or in other words, a given machine can be rated at a higher output as alternate continuous current converter than as continuous current generator, since the alternating current and the continuous current in the armature flow in opposite directions, and thus the current-heating of the armature is due to their difference only, while at the same time the demagnetizing effect exerted upon the field, and the distortion of the magnetic circuit are essentially reduced. Under these conditions the output may be twice as large or even still larger compared with that of the same machine as a continuous current generator.

However, the conditions are different, if besides, a potential control is required from the machine, that is if the machine shall supply constant continuous current potential at the commutator brushes independent of the alternating voltage, within a certain range, which is impressed upon the machine. In this case, by the reaction of the alternating armature current upon the field, which varies with the varying phase relation of the alternating current, and by self-induction, the potential can be controlled so as to maintain the continuous current potential independent, to a certain extent, of the alternating current potential. In such a case the rotary converter must be considerably larger, and be practically of the same size as a continuous current generator of the same capacity.

If I remember rightly, when the question of designing these machines was brought up—it is so long ago that I have nearly forgotten it—we were told that the machines should deliver 160 volts continuous potential, while taking power from a high potential alternating circuit varying from 2,000 to 2,400 volts. This means a variation of alternating current voltage of 20 per cent. had to be controlled by the converter, and for this reason they had to be made as large as you see them. Had it not been for this requirement, we would have designed them considerably smaller.

Regarding the last point, the required flywheel capacity, I cannot agree with the speaker that a flywheel is necessary in a synchronous motor. On the the contrary, in some cases large flywheel capacity is directly objectionable, as in starting a synchronous motor. In starting, the less momentum you have, the quicker the machine will start, and with a heavy flywheel it may not be able to start at all satisfactorily without any external means.

However, under certain circumstances, flywheels may be necessary, especially with machines with weak and unstable magnetic fields which will tend to fluctuate. In this you need a flywheel to steady the motion. In general, however, this is not necessary, and, as far as my experience goes, I never found a case where I required a flywheel to hold a synchronous motor in step.

MR. NEHER:—We certainly find that at slow speed a large armature will have a flywheel effect, and will never be unsteady, and the idea will never strike any one that this machine ought to be kept more steady. In making small revolving transformers though, I think everybody has met with the difficulty of getting the machine to run without pumping. The revolving transformer which has not exactly the same E. M. F. curve as the generating machine, will tend to pump, and if there is a little of that flywheel effect of the armature, this pumping becomes objectionable; in fact, I have experimented with a revolving transformer which I could not ho'd in step at all. As to the question of starting, I think this has been explained already, because the Pittsburgh Reduction converters are going to be started from the outside. Although, as this point has been touched upon, I would be glad to get some exp'anation of it, because as far as I know, revolving converters on two-phase currents are started with extreme ease from their own alternating circuit.

MR. STILLWELL:—It appears to me that some of the members of the INSTITUTE might receive an impression, from the remarks which Mr. Steinmetz made, that the engineers of the Cataract Construction Company were not very confident as to the potential they should be able to deliver at the other end of their lines. The fact which he has stated with reference to the specifications submitted to the engineers who designed the rotary transformers is new to me, and illustrates the difficulties under which the system here at the Falls has been designed and installed. The specification that the generators should be able to deliver their full output at any potential between the limits of 2,000 and 2,400 volts was suggested by our company for this reason: That, looking forward to the time when the machines should be called upon to deliver power for transmission to long distances, we foresaw that it would be necessary to develop in one set of generators used for the long-distance service a higher potential than that used in the other set of generators used for the local circuits. The intention from the start, and the confident assurance of all the engineers concerned in the work, has been that we shall be able to deliver for the local circuits a potential closely approximating 2,000 volts, and for the Buffalo service, or service in still more distant points, the same potential. I understand, from Mr. Steinmetz's remarks, that the specification which the Cataract Construction Company laid before the engineers who designed these rotary transformers, was not properly drawn, and was so stated as to impose upon them very considerable difficulty in the

design. I am interested in the explanation of the exceptionally large size of these machines; but if the specifications had been clearly understood among all concerned, there would have been no reason why they need have been built of increased size in order to act as regulators for the system.

MR. EMMET:—I would say in connection with this that there is a possible misunderstanding. At the time when these propositions were being received and this contract was being closed, the Westinghouse Company had a little bit the advantage of us in the matter of communication with the purchasers, because Mr. Stillwell, as engineer, was communicating with them, and he obtained a correct idea and would have acted upon it undoubtedly. Our engineers were not in direct communication with the Cataract Construction Company, and some misunderstandings undoubtedly crept in. I tried to look up the history of the case but I find that it is impossible to trace it exactly. If the specifications, written or verbal, introduced practical difficulties, I admit there would have been no trouble whatever in getting those difficulties out of the way, since the Cataract Construction Company has always been perfectly willing to accept our advice and has generally allowed us to do work in the manner which we thought best. I think, however, that in this case there was some misunderstanding, and that appeal was never made, because our engineers thought they were tied down to certain conditions and could not avoid them.

MR. STEINMETZ:—I would like to take up the question of flywheels once more. The statement that a synchronous motor tends to hunt if the wave of impressed E. M. F. is different from the wave of counter E.M.F., does not agree with my experience. I have run small machines, as rotary converters of ½ H. P. and 1 H. P., as well as large machines of 400 K.W., and have operated them from machines giving wave shapes entirely different from that of the rotary converter. The rotary converter gave practically a sine wave, with a very small flattening at the top, while the generator, for instance, in one case was a monocyclic machine with a wave shape as mentioned in the last session, containing a triple harmonic of about 24 per cent., and in another case I used as alternator a three-phase machine with a triple harmonic of 12 per cent., a quintuple harmonic of 23 per cent., and a septuple harmonic of 13 per cent., and did not find any tendency whatever to hunt or behave unstable, except in one case where a small rotary converter was highly over-excited and thereby became unstable.

Regarding the starting of these machines, when connecting them directly across the mains while at rest, as it is most desirable for getting a quick start and avoiding the necessity of rheostats and other complications, in such a case the starting current is about 1½ to 3 times the rated or full load current, and the machine runs up to speed from absolute rest in from a few seconds to several minutes time.

MR. NEHER:—This flywheel is a slight curiosity, but I think that the flywheel effect has to be secured, and rather in the shape of cast-iron than of expensive armature and commutator-copper, and this is why, on the power-house converter, that small extra flywheel is to be seen, while on the reduction converters all the flywheel is in the armature itself, and none to be seen outside of it.

I do not agree with Mr. Steinmetz in the statement that a very small revolving converter, running on a different curve than the generator will not pump, because I have seen them pump, and do so with any possible adjustment with any of the field. I have seen them pump with a low field and I have seen them pump on all the steps of the excitation. It may be that this was on account of the special designs of the machines, which were not designed as revolving transformers.

As to the flywheel on the machine which is now in the power-house, I would like to say that this machine has such an exceedingly small armature, of so exceedingly small diameter, although it runs with a speed of 500 revolutions, that the flywheel effect of this machine can in no way amount to the flywheel effect of one of the armatures in the Pittsburgh Reduction power-house; and therefore I still maintain that in those big machines the flywheel effect was secured by a slow speed and very large diameter. I simply think it is cheaper to secure it by high speed and small diameter.

MR. STEINMETZ:—I think I can explain the discrepancy between the observations made by me and those made by the last speaker in regard to the hunting of the machines. The machines I observed were not specially built as rotary converters either, but were standard continuous current motors or generators changed to converters. Still I did not notice any hunting. But most of my experience was limited to three-phase machinery, while the last speaker probably got his experience from quarter-phase machines. Now, if you examine the effect of the higher harmonics, especially that of the triple harmonic, which is generally the most pronounced one, you will see that in the three-phase system the triple harmonics coincide in phase with each other, and thereby annihilate each other in their magnetizing action upon the motor, that is, have no effect at all, while in the quarter-phase machine the triple harmonics combine in a rotary effort which tends to revolve the machine backward at triple synchronism. It was probably this effect which was noticed as hunting by the last speaker, in a quarter-phase circuit, but which does not exist in a three-phase circuit.

PRESIDENT DUNCAN:—This closes the programme of the Twelfth General meeting; a meeting which, for the number in attendance, and the interest displayed, gives great promise for the future of the INSTITUTE.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, September 25th, 1895.

The 99th meeting of the INSTITUTE was held this date at the Hoffman House, and was called to order by President Duncan at 8 P.M.

The Secretary read the following list of Associate Members, elected by Council at its afternoon meeting.

Name.	Address.	Endorsed by
AUSTIN, SYDNEY B.	Electrical Engineer, Sidney, N. Y.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
BLAXTER, GEO. H.	Vice-President and General Manager, Allegheny County Light Co., Westinghouse Building, Pittsburg, Pa.	O. B. Shallenberger. Chas. F. Scott. Alex. J. Wurts.
BOYER, ELMER E.	Electrical Engineer, The Gen'l Electric Co., Lynn, Mass.	H. A. Foster H. Lemp, Jr. Elihu Thomson.
BURT, BYRON T.	Manager and Sec'y. and Treas. Charleston Light and Power Co., Charleston, S. C.	Geo. W. Davenport. E. W. Rice, Jr. A. L. Rohrer.
CARHART, HENRY S.	Prof. of Physics in University of Michigan, Ann Arbor, Mich.	M. I. Pupin. F. B. Crocker. B. F. Thomas.
CORNELL, JOHN B.	Supt. of Construction, with Chas. L. Cornell, Hamilton, O.	S. B. Fortenbaugh. B. J. Arnold. C. L. Cornell.
COSTER, MAURICE	Engineer Westinghouse Elec. and Mfg. Co., N. Y. Life Building, Chicago, Ill.	L. B. Stillwell. Chas. F. Scott. B. F. Thomas.
CRAWFORD, DAVID FRANCIS	Ass't to Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Chas. B. Dudley. F. L. Hutchinson. Leo. A. Phillips.
DAWSON, PHILIP	Associate and Chief Engineer, with R. W. Blackwell, 39 Victoria Street, Westminster, London, Eng.	H. F. Parshall, I. E. Winslow. R. W. Pope.

DEGEN, LEWIS	Constructing Engineer, Gen'l Electric Co., Rio de Janeiro, Brazil.	John W. Kirkland, S. Dana Greene. Maurice Oudin.
DUNLAP, WILL KNOX	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	O. B. Shallenberger. C. F. Scott. L. B. Stillwell.
FRENYEAR, THOMAS C.	Gen'l Manager, Cayadutta Elec. Railway Co., Gloversville, N.Y.	E. N. Sanderson. T. C. Martin. C. J. Field.
HAKONSON, CARL HAROLD	Assistant Engineer, Gen'l Electric Co., P. O. Box 254, Schenectady, N. Y.	Chas. P. Steinmetz. Ernst Berg. H. G. Reist.
HARRISON, RUSSELL B.	Pres. and Electrical Engineer Terre Haute Electrical R'way Co., Terre Haute, Ind.	Ernest P. Warner. Henry H. Wait. Richard H. Pierce.
HARVEY, ROBERT R.	10 So. Franklin Street, Wilkes-Barre, Pa.	W. H. Powell. J. H. Klinck. Wm. J. Hiss, Jr.
HEWITT, CHAS. E.	Graduate Student in Electrical Engineering, Cornell University, residence Hanover, N. H.	Fred'k Bedell. Harris J. Ryan. Ernest Merritt.
HUNTLEY, CHAS. R.	General Manager, Buffalo Gen'l Electric Co., 40 Court Street, Buffalo, N. Y.	H. A. Foster. Ralph W. Pope. Wm. J. Hammer.
IRVINE, D. W.	Student in Electrical Engineering Lehigh University, So. Bethlehem, Pa. Residence, Chambersburg, Pa.	W. H. Powell. J. H. Klinck. R. W. Pope.
KER, W. WALLACE,	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant Street, New York City. Residence, 43 Waverly Street, Jersey City, N. J.	Jos. Wetzler. T. C. Martin. R. W. Pope.
LINCOLN, PAUL M.	Electrician-in-charge, Cataract Construction Co., Niagara Falls, N. Y.	B. F. Thomas. Chas. F. Scott. O. B. Shallenberger.
MANN, ROBERT BRUCE	643 Franklin Street, Milwaukee, Wis.	James Lyman. Alex. Macfarlane. J. D. E. Duncan.
MERRILL, JOSIAH L.	Ass't to Estimating Engineer of the Construction Department, Gen'l Elec. Co., Schenectady, N. Y.	Chas. P. Steinmetz. J. P. B. Fiske. Thorburn Reid.
MERZ, CHAS. H.	with Messrs. Robey & Co., 38 Portland St., Lincoln, Eng. Residence, The Quarries, Newcastle-on-Tyne, England	H. F. Parshall. I. E. Winslow. R. W. Pope.
MITCHELL, JAMES	Constructing Engineer and Agent, General Electric Co., Rio de Janeiro, Brazil.	John W. Kirkland. S. Dana Greene. Maurice Oudin.
MORLEY, EDGAR L.	Superintendent, Hatzel & Buehler, 114 5th Ave., Residence, 107 Lexington Ave., New York City.	C. O. Mailloux. J. C. Hatzel. F. A. Pattison.
PARRY, EVAN	Engineer, The British Thomson-Houston Ltd., 52 Glengarry Road, East Dulwich, London, S. E.	H. F. Parshall. I. E. Winslow. R. W. Pope.

PINKERTON, ANDREW	Electrical Engineer, The Apollo Iron and Steel Co., Apollo, Pa.	W. D. Weaver. Cecil P. Poole. Ralph W. Pope.
POWELL, PERCY HOWARD	Cornell University, Class of '95, residence, Hempstead, N.Y.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
ROBINSON, DWIGHT PARKER	With Stone & Webster, Boston, Mass., Residence, 100 Washington St., Chicago, Ill.	Russell Robb. Chas. G. Stone. Edwin S. Webster.
RUSHMORE, DAVID B.	Student in Electrical Engineering, Cornell University, residence, 168 Grove St., Plainfield, N. J.	Fred'k Bedell. Ernest Merritt. Harris J. Ryan.
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph-Cable Co., N. Y. City; residence, 703 President St., Brooklyn, N. Y.	Francis W. Jones. M. M. Davis. Jas. Hamblet.
STOTT, HENRY G.	Electrical Engineer, Buffalo Gen'l Electric Co., Buffalo, N. Y.	H. A. Foster. Jos. Wetzler. T. C. Martin.
WIESE, GUSTAV ADOLPH,	City Electrician of Alameda, 718 Haight Ave. Alameda, Cal.	Chas. T Lindner. W. F. C. Hasson, Wynn Meredith.
WILSON, CHESTER P.	Sup't 33d and Market Sts. Power Station, Philadelphia Traction Co.; residence, 843 N. 41st St., Philadelphia, Pa.	Ernest Merritt. E. L. Nichols. Harris J. Ryan.

Total, 34.

Mr. Charles S. Bradley read the following paper on "Phasing Transformers."

(See p. 494, June and July issue.)

Discussion.

Dr. Charles E. Emery:—Mr. Chairman, I am very much pleased with the paper and the results here stated. We congratulate Mr. Bradley on the success that has been attained by his efforts, and wish that it may be continued. The details need considerable study, and are perhaps not brought out in detail sufficiently to secure an extended discussion at the present time. I rise, however, to express my appreciation of the work.

Mr. Nelson W. Perry:—I would like to ask Mr. Bradley whether my understanding of this paper is correct—that he will take the ordinary single-phase current and convert that into a multiphase current or polyphase current, and if so, whether it is necessary that there should be a specially designed motor to work with the polyphase current; whether his intention is not to take any single phase current and to convert it into a polyphase current, so that it would operate any make of polyphase motor.

Mr. Bradley:—We have not, so far, made any effort to adopt it for every polyphase motor, but if a standard voltage is adopted every motor of standard make can be used. This motor here is about 75 volts.

The President:—If your load changes, does not your phase change? For instance, you have a single-phase current working a two phase load, or three phase, whatever you want to change it to; now, if your load changes, does not lag change, or something of the kind?

Mr. Bradley:—Yes. But it is so planned that the phases are exactly right for full load. A starting torque is always full load. The phases tend toward single phase at light loads. But the single phase is sufficient to run the light load.

The President:—Yes, I see what you mean. But I think your efficiency would be awfully small.

Mr. Bradley:—No.

The President:—All right.

Mr. Bradley:—Well then, a single phase motor would be of low efficiency.

The President:—Nobody ever denies that at a low period.

Dr. Bradley:—At a low rate.

The President:—At a low rate.

Mr. Bradley:—That is a low rate before it has attained a speed. But in attaining speed and accelerating, your phases come right, because you have the full torque.

The President:—I was speaking of traction work. Is it possible to take your one phase and change that in the car to two or three phase, and get them in such shape that you may start up at any efficiency whatever.

Mr. Bradley:—Yes. It takes full torque at starting.

The President:—Full torque just as if you put in resistance.

MR. BRADLEY:—Yes; of course it needs resistance in the secondary.

THE PRESIDENT:—I see.

MR. BRADLEY:—It needs resistance in the secondary in order to keep the torque. But as long as the resistance is varied in proportion to the speed, why the inductance remains the same, and therefore it maintains the same relation.

MR. JOSEPH SACHS:—I would like to ask Mr Bradley whether the essential difference in diagram Fig. 1 and diagram Fig. 6 is not entirely in the secondary connections.

MR. BRADLEY:—Yes.

MR. SACHS:—And I also understand that Fig. 6 is the Scott method.

MR. BRADLEY:—Yes. Mr President, I will start up the motor and perhaps that will stir up discussion. (Mr. Bradley started the motor). We expected to have had means of showing the torque of the motor but we were defeated in that at the last minute.

MR. SACHS:—Is not that the same motor that you showed at the New York Electrical Society several months ago?

MR. BRADLEY:—The same in principle.

MR. SACHS:—More perfect I suppose.

MR. BRADLEY:—This is 140 cycles. That was 60. The 140 cycle motor is a great deal more difficult.

MR. SACHS:—The principles of construction are exactly the same though, aren't they?

MR BRADLEY:—Yes.

DR. EMERY:—What is the speed?

MR. BRADLEY:—About 2,000.

DR. W. E. GEYER:—I am sorry to say I have not had time to look at this paper. It is evidently very interesting. I think I understood Mr. Bradley to say that these curves that he put down were all true sine curves. Perhaps he has an extra ready way of determining the shape of those curves, and if he has, I think it would be interesting if he would tell us what it is.

MR. BRADLEY:—We do it by the contact method. It is known to almost all the scientific people. There is a telephone and an arrangement of resistance balanced against—do you want a full description of it?

PROF. GEYER:—No. I thought perhaps you had something extra about it.

MR. BRADLEY:—No. But perhaps I had better describe it, as there may be some present who are not familiar with it. There is a disk on the generator that has a very small contact made of thin copper or steel. We are using copper. We hav a hard rubber disk with a saw cut across the surface, and use a watch spring for the brush to make the contact, with a lever to change the position of the brush, and a scale laid off in degrees over which a pointer from the lever moves. One of the terminals

that comes from the contact is carried to one end of the resistance. The other contact is movable along the resistance. Then we take the battery or a direct current from another dynamo and connect with the movable terminal, and with the voltmeter also across that in shunt, and a telephone that is connected in the line leading to the resistance. The contact along the resistance is moved until the telephone is silent, when it shows that the E. M. F. of the machine is balanced against the direct E. M. F. force; and then the voltage is read off on the voltmeter showing the voltage at the moment the contact is made. Now if the contact lever is moved to a zero position of the generator where the wave crosses the neutral line, and the contact is moved until the telephone is silent, the reading then is "no voltage." Then by moving the lever degree by degree, and moving the contact until the telephone is silent each time and reading off, it shows the voltage at each point on the passing of the contact piece in the disk under the brush. In that way we get a complete plotting of the curve of the machine.

Now, if instead of making our connections with the machine, we make our connections at some other point in the system—the motor and transformer or whatever you like, connected with the machine, of course the time period being supplied by the machine, it must therefore rotate in synchronism and read off the E. M. F. and shape of the wave in any of the circuits, between these two in the outside pair, the transformer or any other part of any apparatus that may be in the system connected to that particular machine. We have used it a great deal and found it very successful. The currents are read off in very much the same way, except that we use a resistance in series with the work, and take the drop over the resistance by the same method. This, with small currents, is difficult, but we get sufficient to give us the plotting of the curve. We have not had machines large enough to give a current great enough so that we could get perfectly accurate results as to the current, but accurately enough to show that it is a sine wave.

MR. A. E. KENNELLY:—I cannot say that I have had any experience on this subject as I have had the pleasure of seeing this motor for the first time to-night. But I would like to make a sketch to see if my idea of its operation is a correct one. As I understand it, there are two transformers, one of which is an ordinary transformer and the other of which is a transformer divided in two halves. Now this first transformer produces E. M. F. in the secondary. It may be represented, say, by a straight line, six inches long and horizontal. The second transformer, inasmuch as it contains a condenser and a suitable inductance in circuit, with it produces at full load an E. M. F. which is at right angles to the first. Now those two E. M. F.'s are capable, when united properly in their secondary circuits, of operating a two-phase motor. But the object of the designer in

this case was to operate a three-phase motor, and to do that he arranged it in this way. What is needed in a three-phase motor are three E. M. F.'s at angles of 120° apart like that (illustrating). He takes for the first E. M. F. a portion of this single phase E. M. F. Then he divides the remainder of that up into two smaller and he cuts the vertical one in half and unites a little piece of each horizontal with the vertical in this way, a short piece of the horizontal, then half the vertical, giving a resultant in that direction, 120° off here, so; and then the remainder of the horizontal he combines with this backwards, producing that combination and therefore 120° off here. The three E. M. F.'s at full load are then capable of supplying the triphase system of currents that is needed in the motor. But at light load this combination which gives the E. M. F. at right angles to the ordinary single phase transformer is no longer able to sustain its full value, and these two diminish very much. So that finally you get a close approach to a single phase E. M. F. and a single phase motor. Only at full load currents can you get the triphase combination. Am I right?

MR. BRADLEY:—That is correct. I would like to say that that is all that is necessary.

MR. KENNELLY:—I might say it is not only necessary but important.

DR. CARY T. HUTCHINSON:—It does not seem to me that Mr. Bradley has explained at all why his arrangement in Fig. 6 differs from the arrangement shown in Fig. 1. Why does he split the secondary up into three parts instead of two, and in the other case into two parts instead of one. The primaries are identical. Where does the difference in effect come in? What is the difference in the results?

MR. BRADLEY:—The results are not different. Mr. Scott's plan would require a little less wire, a little less copper, but only a little less.

DR. HUTCHINSON:—Mr. Scott's method does all that Mr. Bradley's does, and it is simple.

MR. BRADLEY:—Yes, it is a little simpler; that is so far as that particular part of it goes.

DR. HUTCHINSON:—Well, what other part of it is there? That is what I asked you. Is there any other part?

MR. BRADLEY:—There is decidedly another part.

DR. HUTCHINSON:—What is it then?

MR. BRADLEY:—I described that in what I styled the combined section of the transformer. The combined section of the transformer gives me a method of phasing. Those are wound interlaced, which gives the two-phase. By running a two-phase motor I would not need to use either Mr. Scott's plan or Mr. Hunting's plan. But in order to convert into three I must use one plan or the other. There is very little difference between the two. Mr. Scott's is a little more simple and requires a little less wire. The invention lies in the primary, not in the secondary. I thought the description was very full as regards that.

MR. HUTCHINSON:—In your diagram the primary is identical with the other diagram.

MR. BRADLEY:—The diagram in Fig. 4?

DR. HUTCHINSON:—Fig. 6 and Fig. 1.

MR BRADLEY:—The essence of the invention lies in getting M. M. F.'s in two cores differing in phase. This is done by means of the condenser and inductance and their connecting circuits, which are wound in opposite directions to produce a resultant in one core while the other core is enclosed by the convolutions of the line leading to the above core vibration, which produces two phases as shown in Fig. 4. Then having the two phases I use these other gentlemen's inventions to convert it from two-phase into three.

MR. F. N. WATERMAN:—I would like to ask one question, if I may, and that is whether these two curves shown in Fig. 7, which show exact three-phase relations, could be obtained equally well from the motor at the period of starting. I understand that this is taken from a half horse-power motor running at full load. What would the phase differences be at the moment of starting.

MR. BRADLEY:—They are the same.

MR. WATERMAN:—They are the same as at full load?

MR. BRADLEY:—Yes.

MR. WATERMAN:—May I ask a question further, and that is, what the departure might be expected to be in a motor, say of the same size, while running at 10 per cent. of its load.

MR. BRADLEY:—Running at 10 per cent. of its load the phases would be quite different. It would approach a single phase condition.

MR. WATERMAN:—I understood. I merely wanted to know if you could tell us about how near that was.

MR. BRADLEY:—Well, I have no exact data to give you now on that question. Perhaps you do not realize that in starting up, the motor really exerts full torque, and therefore the inductance is the same as when running at full load. In such a case as this, where there are two sets of resistances in the armature part, the resistances have to be planned, so that it shall have the same inductance in starting as at full running load.

MR. WATERMAN:—That is the point I had in mind. It is evident that these conditions represented in Fig. 7 are not obtained when you use the other side of the armature, and my point was whether in the condition in which you have it for starting, the three-phase condition is attained with anything like the perfection shown in the diagram.

MR. BRADLEY:—Yes, it is, and that is done by the resistance in the secondary; while accelerating, it is exerting full torque, and the inductance is approximately the same as at full running load. Of course it may be that with that particular armature we have not arrived at exactly the right proportions, but we came near enough so that we have a good starting torque.

DR. HUTCHINSON:—Do you purpose with a large motor to have a double armature and to slide it along from one side to another?

MR. BRADLEY:—Not necessarily.

DR. HUTCHINSON:—This is a double armature practically.

MR. BRADLEY:—This paper is on the subject of the transformer, and the motor is the most convenient one I had at hand to demonstrate with.

DR. HUTCHINSON:—A thing of that kind is absolutely unpracticable for a large machine.

MR. BRADLEY:—Well, I don't know about that.

DR. HUTCHINSON:—I think nearly everybody would agree with me on that point. Why use a double armature when you can do the same thing by having resistance?

MR. BRADLEY:—Of course it is an engineering question that anybody can take up for himself.

DR. HUTCHINSON:—I think anybody will take it against a double armature.

MR. BRADLEY:—That may be. We have had a great many discussions over that subject, and you may be right.

DR. HUTCHINSON:—So may you.

[Adjourned.]

DISCUSSION IN CHICAGO.

PROF. W. M. STINE:—The final decision on such a plan as is here proposed must rest on its commercial value. To some extent such a power system must come in direct competition with the simple motors for continuous current service. The first cost of the polyphase equipment must be relatively high, and its working efficiency must prove somewhat lower than direct current transmission. But this apparatus has another field of application peculiarly its own, to afford a paying day load for the alternating current lighting stations. Judging from what we have seen, it seems reasonable to suppose that the first cost can be brought within such figures as, taking its adaptability and the day load feature into account, would be low enough to enable it to be generally introduced. Mr. Bradley has certainly offered a satisfactory solution of the power problem for single-phase transmission. The problem has been worked out by Professor Rowland, but his solution does not readily lend itself to a commercial form. Others have attempted somewhat similar designs, but have failed because unable to construct a satisfactory condenser. Mr. Bradley seems confident that he has overcome the difficulty and can construct condensers which will prove commercially reliable with high voltage.

This apparatus contains some elements which should make it serviceable for long-distance railway work. From the present outlook, the alternating current is the only mode of electrical power transmission suitable for the work. This would ordinarily

necessitate large transformers placed at frequent intervals. In order to meet the demands of a mixed freight and passenger service, such power transformers would have to be of very great capacity. They could only be used intermittently with the fluctuations of daily traffic, and during most of the time must represent idle capital. The open circuit losses in such transformers taken for the entire system would be a heavy operating expense. Should Mr. Bradley's scheme prove feasible for railway work, these losses would be avoided, for each train would carry its own transformer, from which the idle current could be cut off when not in use. This would result in strengthening the power sections so as to include possibly an entire division served from one central power plant, and, as a consequence, the train load would be practically constant over the day.

NOTICE.

Written discussions of the papers contained in this issue if acceptable, will be printed in the December number if received before December 1st.

The Secretary will esteem it a favor if his attention is called to any errors in either papers or discussion, in order that they may be corrected before printing the sheets for the annual volume.

The Institute as a body is not responsible either for the statements made or for the opinions expressed, in the TRANSACTIONS.

DIED.

CURTISS :—At Boston, Mass., October 10th, 1895, George Franklin Curtiss, Electrical Engineer with the General Electric Company, at Schenectady, N. Y. Mr. Curtiss was born at Derby, Conn., September 2d, 1861. He took a four years' course in electrical engineering at the Massachusetts Institute of Technology, class of '87. He subsequently devoted three years to experimental work in the laboratories of the Thomson-Houston Electric Company, at Lynn, and continued in the service of that company and the General Electric Company until his death. Mr. Curtiss was elected an associate member of the INSTITUTE April 2d, 1889, and transferred to membership Nov. 24th, 1891.

POPE :—At Great Barrington, Mass., October 13th, 1895, Franklin Leonard Pope, formerly of New York City, and Elizabeth, N. J. Mr. Pope was born in Great Barrington, December 2d, 1840. He entered the service of the American Telegraph Company in that town in 1858. His subsequent life was devoted to the study and practice of electrical science. He was a charter member of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, and one of its first vice-presidents, serving from 1884 to 1886, and was elected president in 1886 ; upon the expiration of his term in 1887, he was again elected vice-president for the term ending in 1889.

CUSHMAN :—At his home, 337 West 22d St., New York City, October 24th, 1895, Holbrook Cushman, Head Instructor Department of Physics, Columbia College. Mr. Cushman was 38 years of age, and graduated from Columbia, class of '78. He was appointed fellow in science, and continued his studies at Würzburg, Germany. After returning to this country he engaged in electrical practice with the Western Union Telegraph Company and the Western Electric Company. In 1890 he received the appointment from Columbia College which he held up to his death by heart disease. Mr. Cushman was elected an associate member of the INSTITUTE June 2d, 1888.

MEETING NOTICE.

The 101st meeting of the INSTITUTE, November 20th, will be devoted to a discussion of the "Storage Battery Outlook" and all members having information to impart, bearing upon this subject, are invited to contribute toward a better understanding of the possibilities of the Accumulator. Meetings will be held at New York and Chicago and possibly at San Francisco of which regular notice will be given. Written communications may be sent in at any time. By direction of the Committee on Papers, Meetings and Editing.

RALPH W. POPE, *Secretary*.

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